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Promoting energy transitions: between broad-based access and climate change mitigation

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Promoting Energy Transitions

Between Broad-based Access and Climate Change Mitigation

Thesis

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by Martina Zahno

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Prof. Dr. Katharina Michaelowa (main supervisor)

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Abbreviations

APE	Average partial effect
APEC	Asia-Pacific Economic Cooperation
BDM	Becker-DeGroot-Marschak (a mechanism to assess willingness to pay)
CDM	Clean Development Mechanism
CER	Certified emission reduction
CO	Carbon monoxide
CO2	Carbon dioxide
EnDev	Energising Development (a multidonor energy access partnership)
ESMAP	Energy Sector Management Assistance Program
GDP	Gross domestic product
GHG	Greenhouse gas
GLPGP	Global LPG Partnership
HAP	Household air pollution
IBC	Improved biomass cookstove
IDB	Inter-American Development Bank
IEA	International Energy Agency
IMF	International Monetary Fund
INDCs	Intended nationally determined contribution
INR	Indian Rupee
IPCC	Intergovernmental Panel on Climate Change
ISO	International Organization for Standardization
LCA	Life Cycle Assessment
LPG	Liquefied petroleum gas
NDC	Nationally determined contributions
NRB	Non-renewable biomass
ODA	Official development assistance
OECD	Organization for Economic Co-operation and Development
OPEC	Organization of the Petroleum Exporting Countries
PM2,5	Fine particulate matter smaller than 2.5 micrometer (μm)
PMUY	Pradhan Mantri Ujjwala Yojana (National LPG program in India)
pp	Percentage point (used to compare two different percentages)
RCT	Randomized control trial
SDG	Sustainable Development Goals
SEforALL	Sustainable Energy for All

TPDDTEC	Technologies and practices to displace decentralized thermal energy consumption
SLCP	Short-lived climate pollutants
UN	United Nations
UNDP	United Nations Devleopment Programme
UNFCCC	United Nations Framework Convention on Climate Change
USEPA	United States Environmental Protection Agency
WHO	World Health Organization
WLPGA	World LPG Association
WSSD	World Summit on Sustainable Development (Johannesburg 2002)
WTP	Willingness to pay

1 INTRODUCTION

From basic human needs to economic development and job creation, from social equity to security considerations, energy is at the center of the *Sustainable Development Goals (SDGs)* that global leaders adopted in 2015 under the Agenda 2030. The production and use of energy is at the same time a major source of climate-active emissions, which need to be reduced drastically in order to limit the global temperature increase to well below 2 °C. This goal is in line with the international *Paris Agreement* adopted in 2015 under the United Nations Framework Convention on Climate Change (UNFCCC). In order to achieve the necessary emission reductions in the energy sector, the global economy's dependence on fossil fuels must be curbed to the greatest extent possible, calling among other things for a significantly higher share of renewable energies in the global energy mix and faster progress in promoting energy efficiency. At the same time, the demand for energy will continue to rise rapidly over the coming decades, especially in emerging and developing countries, which makes the challenge even greater.

However, part of the world's population does not even have access to modern energy or cannot afford it, and such energy poverty is an enormous problem on its own. In 2017, 840 million people worldwide were living without electricity and 2.9 billion relied on polluting and unhealthy fuels for cooking (IEA et al., 2019). Access to modern energy services is a basic requirement for all aspects of development through, e.g., health-related benefits, reallocation of household time toward education and income generation, and enhanced productivity in agriculture and industries (Barnes, Samad & Banerjee, 2014).

Hence, economies worldwide face the continuing challenge of improving access to energy and ensuring sufficient and affordable supplies while decoupling economic development from carbon emissions. The transition to such a sustainable energy future is particularly difficult for developing countries. They must satisfy a quickly growing energy demand while major parts of their population continue to live without affordable and reliable access to electricity and clean cooking facilities.

In fact, many governments subsidize the consumption and production of energy based on fossil fuels, justified by the goal of providing affordable energy to the poor and promoting economic development. Fossil fuel subsidies can have detrimental effects on welfare, social equity, and the environment, though, as they distort price signals, incentivize the overconsumption of non-renewable energy, and pose heavy fiscal burdens, while benefiting mostly the wealthier parts of the population (Arze del Granado, Coady & Gillingham, 2012; Burniaux & Château, 2011).

In the context of the Agenda 2030, SDG 7[1] calls for universal access to affordable, reliable, and modern energy, a substantial increase in the share of renewable energy, and much faster improvement in energy efficiency. Accordingly, governments have made efforts – supported by international cooperation – to promote widespread access to basic energy services and to make energy systems more sustainable. This dissertation focuses on two policy areas where advances towards these goals have proved to be particularly difficult. Accordingly, the thesis is divided into two main parts:

In Part I, the thesis discusses subsidies on fossil fuels, whose global volume amounts to several hundred billion dollars annually, further reinforcing the dependence on fossil fuels. Part II of the thesis is devoted to the efforts to improve energy access in developing countries, analyzing the more specific question of the residential use of clean cooking systems, where – despite decades of efforts – progress has been very limited. In the remainder of this introduction, I will present the goals, questions and methods of my research for both topics and discuss their relevance in the respective scientific and policy context.

Fossil fuel subsidies, e.g. in the form of reduced end-user prices or preferential producer treatment, distort prices in favor of fossil energy and therefore lead to wasteful combustion of fossil fuels. As they reach extremely high volumes globally, their phase-out or reduction is potentially a very effective means of reducing greenhouse gases and promoting energy transitions. Beyond the role they play in climate change and energy transitions, on which the work presented in this dissertation will focus, fossil fuel subsidies affect all three dimensions of sustainable development – economic, social and environmental – mostly in a detrimental way.

Regarding climate policy, there has been a debate on market-based instruments, i.e., instruments which work by changing actors' economic incentive structure, for many years, mainly on carbon taxes and emission allowances. Building on Pigou's seminal work on the pricing of environmental externalities (Pigou, 1920) economists have studied and proposed these instruments starting in the early 1970s (Baumol, 1972; Montgomery, 1972; Nordhaus, 1977). Since the early 1990s, researchers and, increasingly, policy makers, have paid a lot of attention to the issue, with about sixty carbon pricing initiatives in place or scheduled for implementation[2] in states and sub-states across the world (data as of February 2020, World Bank, 2020a).

Yet, many environmentally harmful products or activities are currently subsidized rather than taxed.[3] Theoretically, reducing a subsidy affects the markets in the same way as a tax increase. This has been less discussed, though, and energy subsidies only began to be scrutinized explicitly in the 1980s. The first analyses of this kind by economists in international

[1] The 17 SDGs were developed in the aftermath of the United Nations Conference on Sustainable Development in 2012 (also known as Rio+20) and should ensure the promotion of an economically, socially but also environmentally sustainable future (United Nations 2012).

[2] Initiatives are defined as "scheduled for implementation" in the databank if they are formally adopted through legislation and if their launch is planned with an official start date. See https://carbonpricingdashboard.worldbank.org/map_data for more information.

[3] Sometimes they are even subsidized and taxed at the same time, as was the case for petrol or diesel in India for many years.

organizations (IEA, 1988; Kosmo, 1987; World Bank, 1983) focused primarily on the fiscal and macroeconomic costs of energy subsidies. They inspired the subsidy cuts and deregulation of energy prices in the IMF and World Bank structural adjustment programs in many emerging countries in the 1980s and 1990s.

As environmental concerns gained more attention, scholars started estimating the potential CO_2 emission reductions from subsidy removals, with the results of their models suggesting significant impacts (e.g., Larsen & Shah, 1992, see Ellis, 2010 for a review).

Nevertheless, it was only in 2009 that subsidy reform became an international norm, as the leaders of the G20[4] countries committed to reducing and gradually eliminating fossil fuel subsidies at their summit in Pittsburgh (G20 2009). Since then, the growing awareness and pressure from international organizations has triggered reform efforts in many countries. But abolishing fossil fuel subsidies has proved to be a very difficult political task to date, which is why many countries in the G20 and beyond still heavily subsidize the production or consumption of fossil fuels.

Meanwhile, a growing literature has provided evidence for the environmental (Burniaux & Château, 2011), economic (Plante, 2014) and social costs (Arze del Granado, Coady & Gillingham, 2012) of fossil fuel subsidies. It highlights the potential benefits of their removal and examines likely negative impacts of such reforms on the poor and how to mitigate them (Anand et al., 2013; Cooke et al., 2016).

However, subsidies for fossil fuels are often neglected when it comes to the scientific debate on how to increase the share of renewable energies. The price distortions created by subsidies can be expected to affect renewable energy markets and must therefore be considered when assessing any policy mix designed to promote renewable energy. Several studies discuss potential mechanisms by which fossil fuel subsidies can impede the development of renewables (IEA, 2014: 324 ff.; Kitson & Bridle, 2014; Matsuo & Schmidt, 2017; Meier, Vagliasindi & Imran, 2015; Schmidt, Born & Schneider, 2012; Whitley, 2013). Yet, the empirical evidence on these effects is scarce (Bridle, Kiston & Wooders, 2014; Matsuo & Schmidt, 2017; Schmidt, Born & Schneider, 2012) and to my knowledge, no study to date has sought to empirically assess the proposed link on the aggregate level.

In Part I, this doctoral thesis therefore seeks to provide systematic, cross-country evidence on the extent to which fossil fuel subsidies present a barrier to the deployment of renewable energy, even in the presence of policies that also subsidize or otherwise support renewables. To that aim, my co-author Paula Castro and I use panel data from 155 countries between 2003 and 2013 to explore the relationship between subsidy magnitudes and the shares of electricity generated from renewable energy sources (excluding hydropower). We apply descriptive statistics, correlation analysis and a full panel regression model.

Our results for cases where some electricity is already being generated from renewable energy sources suggest that, across countries, higher subsidies for fossil fuels are associated

[4] The G20 (or Group of Twenty) is an international forum for the governments and central bank governors of the twenty leading advanced and emerging economies (19 countries and the European Union).

with a significantly smaller contribution of renewables in the power mix. Yet, when it comes to the likelihood that a country produces *any* electricity from renewables, a stage that we analyzed separately in this chapter, fossil fuel subsidies do not appear to have an impact. The most relevant country-level factors at this stage according to our results are the reliance of a country's economy on oil production, its potential for renewables compared to other countries, its financial support policies for the deployment of renewables and its general environmental performance.

With this study, the thesis contributes to our knowledge of the diverse consequences of fossil fuel subsidies, which is, together with a comprehensive understanding of enablers and barriers to reform, a requirement for successful interventions and policy adaptation.

While abolishing fossil fuel subsidies can support the deployment of renewables and promote energy efficiency, it increases prices for consumers, thereby affecting affordability. The greatest burden can arise for low-income households that may not be able to meet their basic energy needs if energy consumption is not subsidized in some form. This includes electricity for lighting and clean fuels for cooking, which greatly enhance the quality of life, health and opportunities for productive activities. An important example in the context of domestic cooking is liquefied petroleum gas (LPG). It plays an important role in the second part of my thesis, as I shall explain below.

Cooking with solid biomass such as wood and cow dung is a major source of household air pollution (HAP), which in turn is of one of the most important risks for global health. It is estimated that every year, between 1.6 million (Health Effects Institute, 2019) and 3.8 million (WHO, 2019) people die from diseases caused by HAP. Furthermore, cooking with solid biomass in traditional stoves or open fires also causes major environmental burdens (Chafe et al., 2014; Hosonuma et al., 2012), and impedes the empowerment of women and girls.

The widespread introduction of improved, i.e., more efficient and less polluting, cooking technology was therefore praised to have the potential to greatly reduce these burdens (e.g., Smith & Haigler, 2008). Indeed, the deployment of efficient and clean-burning cooking systems – if they eliminate pollution emanating from traditional stoves and fuels and are used sustainably – will contribute to achieving a range of SDGs under the Agenda 2030 beyond SDG 7. These goals include health and wellbeing (SDG 3), gender equality (SDG 5), sustainably managing forests and halting land degradation (SDG 15) or combatting climate change (SDG 13) (Rosenthal et al. 2018).

Accordingly, governments and development organizations have been promoting the transition away from traditional biomass cookstoves towards more efficient and cleaner alternatives with multiple initiatives for more than four decades (Krugmann, 1987). The two most readily available and therefore most relevant technologies today are so-called improved biomass cookstoves (IBCs)[5], i.e., any kind of biomass stove that is more efficient and/or less polluting than traditional stoves and LPG. Other supported systems include those based on

[5] I follow common practice by using the term *improved cookstove* for any kind of biomass stove that burns fuel more efficiently than a baseline stove or removes smoke from the indoor living space through a chimney.

biogas, wood pellets, ethanol and induction. Replacing traditional cooking systems completely may seem straightforward, but has turned out to be very difficult; one reason being that technologies promoted through intervention programmes were not adopted at scale or were not used regularly by consumers. Consequently, despite some encouraging developments in recent years, the number of people using traditional biomass for cooking has hardly decreased (IEA et al., 2018, 2019).

In their efforts to promote cleaner cooking technologies, actors involved in the sector have had different priorities. The focus of major donors in development cooperation has been on IBCs, while several national governments have been running their own programs to promote widespread access to LPG. Most recently, development thinking has somewhat shifted towards so-called *clean*[6] fuels and stoves, i.e., options that reduce HAP very effectively such as LPG, biogas or electricity, as IBCs usually cannot sufficiently reduce health-damaging pollution (Pope et al., 2017).

Yet scholars and institutions in the public health domain argue that clean cooking energy programs[7] have often cited health benefits as an important goal, but primarily focused on other purposes, particularly on climate change mitigation. As a result, donors would largely continue to focus on IBCs and thereby neglect the advancement of health objectives (Goldemberg et al., 2018; Rosenthal et al., 2018; Smith & Sagar, 2014). There are hence fundamentally different views on the issue of residential household energy among donors, with potentially significant developmental consequences.

Our understanding of how the priorities of various groups of actors are currently evolving and why they differ so much is insufficient. While scholars from the "clean-fuel camp" argue that the focus of bilateral donors on IBCs is rooted in a dominance of the climate agenda in the discourse and actions of international sustainable development (Goldemberg et al. 2018), there is little empirical evidence on whether and by which mechanisms climate policy influences development cooperation in the field of household energy.

In my second study, presented in Part II of this thesis, I therefore aim to identify and explain the different positions of donors on clean cooking interventions by exploring what is shaping their priorities. The analysis focuses on LPG and IBCs, which have been the two globally dominant options in government programs and development cooperation. More specifically, I seek to examine how actors' priorities in clean cooking programs are influenced by economic incentives, political interests and power, which are in turn shaped by institutional structures and norms. To do so, I use an analytical framework that is based on a rational choice approach and draws on findings from the political economy of aid and the climate finance

[6] In line with the major international organizations promoting energy access, notably the International Energy Agency and the United Nations, I consider *clean cooking facilities* to be modern fuels and technologies that minimize emissions that are harmful to health and the environment. These include natural gas, LPG, electricity and biogas or improved biomass stoves with much higher efficiency and significantly lower emissions than traditional stoves or open fires. As of today, only few improved biomass stove models meet this lower emissions goal, especially under real-world conditions for cooking, as Chapter 4.1. will discuss comprehensively. For more information see, e.g., https://www.iea.org/articles/defining-energy-access-2019-methodology.

[7] Since most organizations today generally use the terms 'clean cooking', 'clean cookstoves' et cetera (regardless of whether the technologies being promoted are clean in the above sense), I will, for the sake of simplicity, refer to *clean cooking* when speaking about any *program* or *intervention* in this area or about the *sector* as a whole.

literature. The empirical analysis is informed by the academic literature on clean cooking interventions and climate finance, policy documents and the interpretation of these documents. I complement and cross-validate this evidence with self-collected data from a survey among representatives of major organizations in the sector and from in-depth interviews with key informant experts.

My findings suggest that international climate policy – through emission reduction targets, public climate finance and carbon markets – has so far provided strong political and economic incentives for bilateral donors to continue focusing on biomass when providing support to energy programs related to cooking.

Meanwhile, as mentioned above, several countries have been promoting widespread access to LPG themselves. The Indian government in 2016 launched one of the most important of these programs, the *Pradhan Mantri Ujjwala Yojana* (PMUY). As the PMUY covered the upfront cost for access to this clean fuel, the number of households registered as LPG users increased by 80 million within just over 3 years. This is a development of unprecedented scale. However, so far, many households who adopted LPG under the program continue to rely on traditional biomass for a major part of their cooking (Kar et al., 2019). Multiple fuel use (so-called *fuel stacking*) is a widespread phenomenon and may persist over a long time (Cheng & Urpelainen, 2014; Masera, Saatkamp & Kammen, 2000).

Within the context of this program, I examined the effectiveness of additional measures to achieve sustainable LPG consumption among low-income households together with Katharina Michaelowa, Purnamita Dasgupta and Ishita Sachdeva. This third study is presented in Part II of the thesis. It adds to the debate among scientists and practitioners on the major difficulties to rapidly provide nearly 3 billion people with access to clean cooking systems. In this context, researchers have been studying household energy choices, the obstacles to widespread use of cleaner cooking systems and ways to overcome them since the 1980s (e.g., Barnes et al., 1994; Lewis & Pattanayak, 2012).

A significant proportion of these studies has focused on improved biomass stoves, and within the research that is concerned with clean fuel transition, most work is concerned with technology adoption (e.g., acquirement of an LPG stove) rather than with the technolgy's actual use as primary cooking system. However, several drivers can of course be important in both contexts.

Concerning the use of LPG as primary fuel among new users in rural India, the cost of regular refills and supply-side constraints are considered as key obstacles (e.g., Cheng & Urpelainen, 2014; Gould & Urpelainen, 2018). In addition, households may be unaware of the important health benefits of LPG and therefore not recognize a need to change fuel consumption. While consumers hold positive views of LPG as a timesaving, convenient and clean fuel (Gould & Urpelainen, 2018), this alone may not prompt them to switch to its sustained (or even dominant) use. Hence, providing clear health information could be a key measure to support the transition to sustained use of clean cooking fuels.

Related scientific work has shown that information on health benefits does not necessarily change the behaviour of users (Beltramo et al., 2015; Mobarak et al., 2012). However, as far as we know, this has never been tested in the context under consideration. The closest existing research focuses on LPG use in Kerala and Uttar Pradesh (Krishnapriya, 2017) and on the willingness to pay (WTP) for improved biomass stoves in rural Bangladesh (Mobarak et al., 2012), where the up-front costs of purchasing stoves were relatively high and represented an important barrier (see also Bensch & Peters, 2015). The paper presented in this thesis now examines the impact of health messaging in a context where the issue of high up-front costs has already been resolved by the PMUY. We expect that with these new conditions, the impact of health messaging on WTP and LPG consumption could be significant.

Our evidence is based on a survey of 554 households in the rural part of Bikaner district in Rajasthan. We randomly assigned health information to one part of the respondents and general, non-health-related information on LPG to the other part. We then measured the treatment effect on two variables. First, the necessary financial compensation to induce households to double their LPG consumption at given prices, and second, the actual increase in consumption, measured by the households' use of a voucher for a new refill before a given deadline.

Our results are encouraging. They show that health messaging increases the reported willingness to pay for LPG and substantially increases actual consumption. We further show how the impact of our very brief, but concrete health messaging compares to price reductions for new LPG cylinders and discuss why it may be useful to target not just women, but also men.

Overall, in the second part of my dissertation I aim to improve our knowledge of energy access interventions, notably by enhancing our understanding of donors' priorities in this policy area as well as by providing evidence on the effectiveness of health messaging as a complementary policy measure.

The research on climate- and energy justice is related to the strands of literature in the field of energy access: It addresses similar issues of energy and climate decisions to those discussed here, albeit from a normative perspective (e.g., Edenhofer et al., 2012; Jones, Sovacool & Sidortsov, 2015; Sovacool et al., 2016). As it would go beyond the scope of this thesis, I will not consider the normative perspective in the assessment of energy access measures. Nevertheless, the policy area raises a range of questions that are worth addressing. An important one is under which circumstances, based on considerations relating to climate or energy justice, the large-scale promotion of LPG as primary cooking fuel would be justifiable as a means to universal access to clean energy for sustainable development.

The remainder of this doctoral thesis is structured as follows. Part I, which focuses on fossil fuel subsidies, sets out with a review of the scientific evidence on the scope and effects of fossil fuel subsidies in Chapter 2. This chapter also describes how international politics has addressed the issue and discusses the arguments that scholars have put forward to explain the persistence of fossil fuel subsidies. Chapter 3 then contributes to our knowledge on how fuel subsidies affect the deployment of renewable energies. It examines whether fossil fuel subsidies present a barrier to the deployment of electricity from renewables on the aggregate level, even in the presence of policies that also subsidize or otherwise support renewable energy.

In Part II, which is devoted to clean cooking, Chapter 4 introduces the reader to clean cooking as a policy issue in development and to the scholarly discussions surrounding it by reviewing literature from multiple research disciplines, including public health, climate and environmental science, and development economics. It starts by summarizing the environmental and public health problems associated with the use of traditional biomass for cooking and heating and discusses the most recent scientific evidence on some of the available alternatives to traditional cooking fuels and stoves. It concludes with a review of the scientific evidence on the energy consumption decisions of (poor) households and on enablers and barriers to widespread use of clean cooking technologies.

Chapter 5 then traces the efforts that have been made by national governments and the international community from the 1970s onwards to provide access to cleaner technologies and how they have been shaped by the prevailing understanding of the issue. It is informed by the academic literature on clean cooking interventions and climate finance, policy documents and the interpretation of these documents. The promotion of clean cooking technologies can lead to trade-offs between climate mitigation and public health with non-negligible consequences. Chapter 6 therefore analyzes the political, economic and ideational factors that shape the strategies of donors in the field of clean cooking. Finally, Chapter 7 looks at the challenges at the household level and presents a field study in India in which the effectiveness of awareness campaigns with respect to the consumption of clean fuels was tested. Chapter 8 concludes with a summary of my main findings and their implications for policy and further research.

PART I
SUBSIDIES TO FOSSIL FUELS

2 FOSSIL FUEL SUBSIDIES AS A BARRIER TO SUSTAINABLE DEVELOPMENT

At the Paris climate conference 2015, parties of the UNFCCC passed a new global climate change agreement that aims to limit global warming to well below 2 °C, and to take efforts to keep the temperature increase at 1.5 °C. In order to achieve the climate goals under the Paris Agreement, greenhouse gas emissions must be drastically reduced. In this context, a key concern is to reduce the consumption of fossil fuels, the largest source of carbon dioxide (CO_2) emissions. For many years, the policy debate in this area has been focusing on strategies based on taxes, emission allowances, statutory emission standards and other regulatory instruments. At the same time, fossil fuels are receiving strong support from governments around the world, for instance in the form of reduced end-user prices or preferential producer treatment. As global subsidies to global fossil fuels reach very high volumes, their elimination or reduction is a potentially highly effective instrument to combat climate change and promote energy transitions. Yet, the political economy and the social aspects surrounding fossil fuel subsidies are complex and mean that reforms are not at all simple. For instance, various groups such as consumers, energy intensive manufacturers or extractive industries have an interest in retaining these subsidies. Some of these groups are well organized and have close links to policy makers.

This chapter first provides a review of the scientific evidence on the scope and effects of fossil fuel subsidies. It then describes how international politics has been addressing the issue and discusses the arguments that scholars have put forward to explain the persistence of fossil fuel subsidies.

2.1 Definitions and estimates

There is no commonly agreed definition of fossil fuel subsidies on the international level. However, the Organization for Economic Co-operation and Development (OECD), the International Energy Agency (IEA) and the World Bank defined *energy subsidies* very broadly as "[...] any government action that lowers the cost of energy production, raises the revenues of energy producers or lowers the price paid by energy consumers" (IEA, OECD & World Bank, 2010: 5). This definition recognizes that governments use a whole range of instruments to transfer value to certain forms of energy and reduce their risk, and that these instruments often do not involve direct disbursement of money.

Amongst the manifold types of fossil fuel subsidies that commonly exist, those which predominantly aim at lowering end-user prices for transport fuels (petrol and diesel), gas and kerosene used in homes and fuels for electricity generators and domestic industries remain most prevalent in developing countries (IEA, 2014). The purpose of such consumer subsidies is typically to provide poor households with access to energy and transport and to promote economic development. Governments put this type of subsidies in place through, e.g., prices set below the market price, reduced rates for retail taxes and public support to the distribution infrastructure.

Producer subsidies on the other hand lower the production costs of oil, gas and coal, and typically aim at encouraging an expansion of domestic energy supply or supporting the export thereof. Examples of producer subsidies (in a wider sense, as defined above) include tax exemptions, low-interest loans, grants, or insurance at favorable conditions for energy producers such as fossil fuel exploration and extraction companies or state-owned oil companies (OECD, 2013). These forms of preferential treatment are less transparent than consumer subsidies, which is why producer subsidies can be difficult to detect and their magnitude challenging to quantify. Many G20 countries strongly support their domestic oil production, but several poorer countries and emerging economies also do (Rentschler & Bazilian, 2017).

To define and estimate global subsidies, a number of different concepts are applied. In this context, one can distinguish between two main approaches. One is the *inventory-approach*, which identifies the government measures to support market participants and quantifies the resulting transfer (OECD, 2013). The other is the *price-gap approach*, assessing the difference between the observed and the 'free market', or benchmark price of an energy product (cf. Koplow, 2018, also for strengths and limitations of the two strategies). Consumer prices below the benchmark or rates paid to producers higher than the benchmark are hence defined as consumer and producer subsidies respectively. The benchmark price is generally based on the global market rate, and, for consumer subsidies, includes financial costs such as transportation- and distribution costs or the domestic VAT. Inventory- and price-gap approaches are also combined, notably in the OECD's total support estimate (TSE), to assess the total of (i) price distortions and (ii) transfers that do not affect retail prices, on the producer as well as the consumer side (Koplow, 2018).

The most important estimates of total global subsidies are those produced by the IEA, the OECD and the IMF. These organizations' estimates vary in terms of the main approach applied. In addition, there are differences regarding further conceptual issues, geographical coverage and other factors, including data issues each approach is facing. The most widely employed values are those by the IEA. They are based on annual assessments of subsidies in 40 countries using the price-gap approach. The OECD, based on its TSE approach, draws up inventories of government support for the production and consumption of fossil fuels and for general industrial infrastructure. The OECD estimates are also covering about 40 countries, but mainly comprise advanced economies[8], while the IEA data include far more developing countries (IEA, 2019b).

The IMF, assessing the value of subsidies in 153 countries, provides the most comprehensive data. The organization's *pre-tax* subsidies result from a blend of estimates from both the IEA and the OECD, supplemented by internal estimates for other countries. The IMF further produces *post-tax* subsidy estimates, which include a hypothetical national sales tax, which accounts for price levels that are too low, according to the IMF and, primarily, for negative externalities associated with fossil fuel use such as local air pollution and climate change (Coady et al., 2015; IMF, 2015; Shang et al., 2019).

These differences result in largely diverging estimates of the size of global subsidies. A compilation by Koplow (2018: 32) that allows comparison across sources, global subsidies to fossil fuels in 2014 reached $506 billion U.S. dollars according to the IEA, $170 billion according to the OECD and $333 billion (pre-tax) or $5.3 trillion (post-tax) according to the IMF.[9] Since the IEA estimates only account for a limited number of countries and do not take all government measures into account, the values must can be regarded as a lower bound (Skovgaard & van Asselt, 2019). Regarding the upper-bound estimate provided by the IMF, the inclusion of large externalities (mainly health-related ones linked to coal) is controversial among some practitioners (Koplow, 2018).[10]

Notwithstanding the differences outlined above, these estimates indicate very high volumes of global fossil fuel subsidies. In several countries – namely countries in Central Asia and the Middle East, but also India – subsidies reached a relevant share of the gross domestic product (GDP) (Coady et al., 2015).

As observed consistently by the IMF, the IEA and the OECD, global subsidy volumes peaked in 2012/2013 and then decline significantly until 2016. The downward trend was to some extent attributable to fuel price deregulations and reforms of subsidies, but are mainly driven by the decline of international oil prices during this period (IEA, 2019b; OECD, 2018; Shang et al., 2019). In line with this, when international oil prices rose again in 2017 and 2018, this was reflected in an increase in global oil subsidies, at least according to the estimates of the IEA and IMF (ibid). As an example, according to the IEA estimates, total government support to fossil fuel consumption was $276 billion in 2016 and went up again to $427 billion in 2018 (IEA, 2019b)

[8] In their 2017 inventory, the OECD (2018) covers the OECD members plus eight major other countries such as India, China and South Africa.

[9] All estimates in 2015 U.S. dollar.

[10] A detailed discussion of subsidy definitions, global estimates, main causes of differences in estimates and measurement gaps is given in Koplow (2018).

2.2 The economic, social and environmental impact of fuel subsidies

2.2.1 Inefficiency and economic loss

According to standard economic theory subsidies to fossil fuels create distortions of resource allocation (Mc Lure Jr., 2014). Subsidies lower the price paid by consumers and thereby drive a wedge between the value of each unit of consumption (approximated by the market price) and its actual (subsidized) price. This results in overconsumption of subsidized fuel (e.g., Al Iriani & Trabelsi, 2016) and keeps inefficient producers alive on the supply side. Hence, fuel subsidies would be causing a deadweight loss, even if there were no environmental impacts of fuel consumption. Evidence from partial- or general equilibrium models generally supports that energy subsidies reduce total welfare (Burniaux & Château, 2011; Davis, 2014; Plante, 2014).

2.2.2 Fiscal costs

Fossil fuel subsidies further impose high fiscal costs. In the course of high and rising fuel prices after 2009, government expenditures on energy subsidies contributed in many countries to a fiscal burden, which was difficult to sustain. In countries of the Middle East and North Africa region for instance, fossil fuel subsidies reached on average almost 20 % of total public expenditures in 2013/2014 (El-Katiri & Fattouh, 2017). Fossil fuel subsidies thus crowd out other expenditures potentially more essential for development, like expenditures for education or health, which has arguably adverse effects on the economy (Anand et al., 2013; Dartanto, 2013). Iran, for example, spent 15.3 % of GDP in 2018 on subsidies for fossil fuels, almost four times as much as on education (4 %) (IEA, 2019b; World Bank, 2020b). In Kazakhstan, subsidies were 5.4 % compared to 2.8 % for education. A similarly small budget for health care is available in these and other countries compared to subsidy expenditure.

2.2.3 Socioeconomic impacts

Especially in low-income countries and emerging economies, governments commonly justify fossil-fuel subsidies as a means to assist the poor to gain or maintain access to essential energy services or as an instrument for income redistribution (Commander, 2012; Rao, 2012). Yet low-income households frequently lack a connection to the electricity grid and do not own motorized vehicles either (IEA et al., 2019; UNDP & WHO, 2009). Further, energy consumption is generally higher amongst wealthier households. For these reasons, it is usually the more affluent households that receive the bulk of the subsidy payments, as shown by empirical evidence from numerous countries (Arze del Granado, Coady & Gillingham, 2012; Coady et al., 2006; IEA, 2011). Income benefits and the progressivity of fuel subsidies in developing countries vary significantly across fuels and depend on regional consumption patterns (Dube, 2003; Rao, 2012).

Yet, even though the majority of subsidies benefit the wealthier households, reducing subsidies and exposing the poor to the volatile market prices can result in a substantial decrease in those households' real income (Coady et al., 2006). Also, regarding residential energy use, higher prices for modern energy can lock poor people into using solid fuels for cooking (Fay et al., 2015; Garg et al., 2017). Hence, ensuring that poor households obtain and retain access to modern energy services is very important. In this context, interventions to increase access to basic modern residential energy services such as electricity and clean fuels can have substantial development impacts (e.g., Barnes, Samad & Banerjee, 2014; Khandker, Barnes & Samad, 2013b, Bruce & Ding, 2014), whereby providing access to low-income households often requires subsidizing appliances and energy use.

If they are successfully targeted at extending access to modern energy products to poor households, subsidies can therefore be an effective measure for poverty reduction. Most studies on the social impacts of fuel subsidies neglect these possibilities though and focus on the regressive distribution of subsidy benefits.

2.2.4 Environmental impacts: climate change and health

Fossil fuel combustion is associated with negative external effects such as climate warming and health risks from air pollution. The subsidized price hence lies even further below the optimal (or efficient) price for fossil fuels, resulting in greater levels of greenhouse gas emissions and local air pollution.

Estimates show that 4.9 million premature deaths are attributable to air pollution in 2017 (Health Effects Institute, 2019). The combustion of fossil fuels in motor vehicles, for heat and power generation, in industrial and agricultural processes, and the use of polluting fuels in residential cooking, heating and lighting are major sources of air pollution. Hence, there is generally a strong link between deteriorated air quality caused by fossil fuel combustion and the global health burden, even though it is difficult to attribute individual health effects to specific sources of pollution. Since subsidies for fossil fuels encourage their use, phasing-out such support could cut mortality from air pollution massively (Coady et al., 2015). In the specific context of household air pollution, energy subsidies increase the consumption of both, polluting fuels like coal and kerosene, and of cleaner energy sources such as LPG and electricity.

Fuel subsidies further contribute to climate change, through several mechanisms. One is that artificially lowering production costs or consumption prices directly incentivizes excessive consumption of fossil fuels. Hence, fuel subsidies cause higher CO_2-emissions (IEA, 2015a; Stefanski, 2014).

In addition, fossil fuel subsidies are a driver of carbon lock-in, because they support fossil fuel consumption and production instead of low-carbon alternatives (Newell & Johnstone, 2018). Carbon lock-in is commonly understood as an example of path dependence, where favorable economic and social conditions in the beginning, increasing returns to scale and dynamics at the individual and societal level have led to an inertia of the system, which inhibits the (rapid) transformation to a low-carbon society (Seto et al., 2016). Carbon lock-in is associated with the infrastructures and technologies that shape the energy supply, with the political decision-making processes and institutions that affect energy production and consumption patterns and with behavioral patterns and norms, related to the consumption of energy-related products (ibid.).

Consequently, abolishing fossil fuel subsidies would reduce greenhouse gas emissions significantly in the longer term. Recent estimations report that global greenhouse gas emissions could be 8 to 10 % lower if all countries jointly removed their subsidies, relative to a business-as-usual scenario (Burniaux & Château, 2011; IEA, 2014). Coady et al. (2015) estimate a more drastic reduction of CO_2 by 20 %, which is plausible given that the authors base their estimations on the notion of post-tax subsidies. Schwanitz et al. (2014) confirm the benefits of phasing out fuel subsidies, while emphasizing that in the long-term, reductions of greenhouse gas emissions can only be realized to a small extent if phase out is not complemented by climate policies. Otherwise subsidy phase out could even slow down a global transition towards a renewable based energy system, as a removal of subsidies could lead to a drop in world market prices for fossil fuels. Results from modelling studies like those discussed above need cautious interpretation, as their results depend heavily on the underlying assumptions. In particular, price elasticities of fuel demand is a very controversial subject in the literature (e.g., Dahl 2012).

A particularly important concern linked to the carbon lock-in effect of fuel subsidies is their impact on the generation and use of renewable energy. For instance, using spending cuts from the reform of fossil fuel subsidies to support the deployment of renewable energies would lead to further emission reductions. More generally, there is a price distortion resulting from fossil fuel subsidization, which is likely to affect the market for renewable energies (even if public savings from reform are not re-allocated to renewables). That is, the availability of underpriced fossil fuels encourages their continued use at the expense of other energy types, particularly renewable energy (Meier, Vagliasindi & Imran, 2015). There is however, to the best of my knowledge, hardly any empirical evidence on the effect of fossil fuel subsidies on renewable energy deployment. Chapter 3 addresses this gap in the literature.

2.3 International politics of fossil fuel subsidy reform

Against the backdrop of their adverse effects, fuel subsidies have moved up the political agenda and international organizations have been making considerable efforts to push for reductions (Rentschler & Bazilian, 2017). The need for reform receives international attention at least since the summits of the G20 and the Asia-Pacific Economic Cooperation (APEC) in 2009, where governments vaguely committed to phasing out ´inefficient´ fuel subsidies (G20 - Group of Twenty, 2009). These initial commitments were mainly driven by the contribution of fuel subsidy reform to sound fiscal policy, climate change mitigation and energy security.

Social equity and sustainable development have increasingly entered the debate as further arguments for reform, however (Fay et al., 2015). In the declaration of the United Nations' (UN) Rio+20 conference for instance, countries emphasized that sustainable development would be undermined by fuel subsidies and reaffirmed their commitments to reform (UN, 2012). Similarly, communiques of multilateral conventions like APEC (2013), G20 (2014) and the 'Friends of Fossil Fuel Subsidy Reform (FFFSR)'[11] reflect the notion of combined environmental, economic and social benefits. The World Bank, the IMF, the UN, the IEA and the Intergovernmental Panel on Climate Change (IPCC) have all become strong supporters of subsidy reform on behalf of climate change mitigation and sustainable development (UNEP-IMF-GIZ-GSI Workshop, 2014; Vagliasindi, 2013).

The World Bank has played a particularly important role in the international political efforts to reduce fossil fuel subsidies, especially in low-income countries (Skovgaard & van Asselt, 2019). Through analytical work, but also through conditionalities (as part of structural adjustment programs), the Bank has promoted fuel subsidy reform since the 1980s (ibid.).

Most recently, the World Bank, as well as the European Investment Bank, declared that they would refrain from investing in fossil energy production in the future, in an effort to support low-carbon development (European Investment Bank, 2019; World Bank, 2017b).[12]

During the 2015 UNFCCC conference in Paris, explicit references to phasing out fossil fuel subsidies were only made at side-events, which are not part of the official negotiations and mostly organized by external actors.[13][14] Nevertheless, the Paris Agreement implicates a clear commitment to promoting low-carbon energy transition. According to Terton et al. (2015: 3), 13 countries have included the reduction of fuel subsidies in their intended nationally determined contributions in the run-up to Paris. Eventually, nine of these included fossil fuel subsidies reduction in their nationally determined contributions (NDCs) (UNFCCC, 2020). The issue fully entered the mainstream development agenda when fuel subsidy reform was included as sub-goal Goal 12.c in the SDGs in 2015 (UN, 2015: 19).

Energy subsidies are still larger than the total bilateral aid in 59 % of recipient countries though and the donor community has devoted only few resources to supporting low-income countries to remove energy subsidies, apart from providing analytical work in support of international diplomatic efforts (McCulloch, 2017). Indeed, there is only limited scope for development projects in this area. Moreover, the low level of effort may be linked to the political sensitivity of fuel subsidy reforms. This issue is further discussed below.

[11] FFFSR is an informal group of non-G20 countries that aims at building political consensus on the relevance of fossil fuel subsidy reform within forums like G20, APEC, World Bank, OECD, Sustainable Energy for All (SEforALL) and the SDG Agenda. Current members of the group are Costa Rica, Denmark, Ethiopia, Finland, New Zealand, Norway, Sweden, Switzerland and Uruguay. In addition, more than 30 countries and 50 organizations have endorsed FFSR. See http://fffsr.org/ for more information.

[12] However, both reports suggest that under certain circumstances these banks will continue to support energy projects that contribute to the aims of the 2030 UN Agenda for Sustainable Development, particularly ensuring universal energy access.

[13] Notably, the International Institute for Sustainable Development organized a side-event titled "Fossil Fuel Subsidies and Climate Change: national action and international phase out". For more information see https://unfccc.int/files/side_events_exhibits/application/pdf/cop21cmp11_indc_side_events.pdf

[14] A suggestion that called on countries to reduce international assistance for emissions-intensive investments appeared in an earlier draft text during the negotiations in Paris, but was removed from the final version. See van de Graaf & Blondeel (2018).

2.4 Persistence of fossil fuel subsidies

While the adverse consequences of fuel subsidies and the need for reform are politically widely recognized, actual policy responses rarely involve a complete subsidy phase-out. Governments often prefer adopting reforms that encompass reducing subsidies, introducing better control mechanisms to reduce leakages or improving their targeting. In general, while low international oil prices have favored the phase-out of subsidies in recent years, actual progress on reform has been very slow (Clements et al., 2013; Rentschler & Bazilian, 2017).

Especially low-income and emerging economies are facing strong political barriers to reform subsidies (Lockwood, 2014). As a consequence, reforms are rare and sometimes reversed shortly after implementation (IEA, 2014: 313). Attempts to reduce fuel subsidies have often triggered violent protest, for instance in Nigeria, Sudan, India or Jordan in recent years. A prominent example is Indonesia, where the long-time authoritarian leader Suharto was arguably forced to resign in 1998 following riots against a government-led raise of fuel prices by up to 70 per cent (Lockwood, 2014).

A growing literature is looking into why fuel subsidies are so pervasive despite their adverse effects and why governments usually maintain them, even after the initial goals, such as ensuring a particular level of domestically produced energy or helping the industry to adopt a new technology, have been achieved (IEA, 1999; OECD, 2007).[15] In one of the first political economy analyses of fossil fuel subsidies with a stronger focus on developing and transition economies, Victor (2009) noted that subsidy policies are determined by a combination of purely interest-based political purposes and "legitimate purposes". The latter means goals such as transferring and redistributing income to the poor, supporting export or infant industries or diversifying energy supply. And once the subsidy policy is in place, "[...] regardless of its original purpose, interest groups and investments solidify around the existence of the policy and make change difficult" (Victor, 2009: 7).

Regarding downstream or consumer-oriented subsidies, Victor argues that they are "populist subsidies" (ibid.), initiated (at least initially) by the government to visibly transfer benefits in exchange of political support. The high prevalence of fossil fuel subsidies in major oil producing countries might be seen in this light: as incomes from natural resources have been regarded as national wealth to be shared across all citizens, subsidies represent popular policies to channel these rents to the citizens (Segal, 2012: 344). However, political demand and influence alone cannot explain the prevalence of subsidies.

Some scholars argue that fossil fuel subsidies may be chosen in particular by elites of authoritarian states fearing instability and overthrow and that subsidy reform is more difficult in non-democratic states (Commander, 2012; Victor, 2009). An explanation for this populist paradox is the fact that income and wealth tend to be distributed more unequally in non-democratic regimes. Subsidies are a credible means of providing income to the general population,

[15] As discussed in 2.2.3, there can be a rationale for ongoing public support if people cannot/choose to consume less than the socially optimal level of electricity or clean fuels. However, social security measures targeted to the poor are considered much more effective though.

even if de facto the elites benefit most from them. Authoritarian regimes also provide fewer public goods (Bueno De Mesquita et al., 1999) and that further impairs the chances to change policy, e.g., in response to exogenous shocks such as an international price hikes (Commander, 2012).

More generally, scholars emphasize the need to look at the factors that lie beyond demand and condition the willingness and ability of governments to supply subsidies. According to Commander (2012), governments sometimes use subsidies because they lack other effective levers or institutional capacity to implement public policies. Notable examples may be the expansion of public transport or social security systems. Also, these governments may have problems with credibility and capacity to reform (Commander, 2012). In non-democratic regimes, since they are commonly related to weaker institutions, subsidies are readily available mechanisms that require very little administrative capability.

Some empirical evidence on subsidy provision across countries exists for gasoline pricing. One of the most important factor behind governments subsidizing fossil fuels is the fact that these governments themselves are major oil producers. Offering fossil fuel products at low prices is relatively easy for them and, as mentioned above, citizens expect that rents from national oil-production are shared (Baig et al., 2007; Cheon, Urpelainen & Lackner, 2013; Ross, Hazlett & Mahdavi, 2017). No substantive and consistent effects have been identified for several general indicators of institutional quality such as bureaucratic capacity and corruption. However, according to Cheon, Lackner & Urpelainen (2015), the presence of a national oil company as a specific form of resource governance, is associated with significant subsidies on petroleum products, since governments use these companies to mitigate impacts of rising international oil prices. The same group of researchers also provided empirical evidence for the aforementioned proposition that subsidies are systematically higher in autocracies than in democracies (see also Cheon, Urpelainen & Lackner, 2013).

Once governments are willing to implement reforms, the opposition of citizens is likely to present a major constraining factor on them. A key determinant of public opposition to reform is the adverse effect of subsidy cuts on people's economic welfare. In this context, even though in absolute terms, the rich obtain most subsidies, the adverse effects of removing subsidies are thought to be most severe for the poor, relative to income (Arze del Granado, Coady & Gillingham, 2012; IEA, OECD & World Bank, 2010).

Another constraining factor for public acceptance is that the population is mostly far from being accurately informed on what subsidies consumers or producers receive and how the subsidies are financed (e.g., Commander, 2012).

To improve public support, policy experts commonly suggest to use a part of the savings from eliminating subsidies for better targeted transfers or other development measures to compensate the poorest households (Baig et al., 2007; Mc Lure Jr., 2014; Vagliasindi, 2013). Policy recommendations further include extensive information campaigns and a clear scheduling of gradual price increases, communicated in advance (Beaton et al., 2013; Clements et al., 2013; Dansie, Lanteigne & Overland, 2010).

However, it is still the case that "reform is almost universally politically controversial" (Lockwood, 2014: 2). Most often governments do not get through fuel subsidy reforms, even in democratic contexts and when the magnitude and shortcomings of fossil fuel subsidies are recognized, and sometimes even if reform is expected to benefit the majority of the population (Calvo-Gonzalez, Cunha & Trezzi, 2015).

The literature which shows that individual uncertainty may lead to a status quo bias can partly explain why policy makers regularly fail to persuade the electorate of the benefits of a policy change (Fernandez & Rodrik, 1991). Evidence from case studies on subsidy reforms suggests that uncertainty stems inter alia from the public's lack of confidence in the government to use savings from subsidy reform wisely.

The discussion of the literature above emphasizes the importance of appreciating the political-economic aspects of subsidy reforms. Some of these have not yet been comprehensively addressed in the literature. This thesis, however, hereafter focuses on the consequences of fuel subsidies in the context of energy transitions

3 THE EFFECT OF FOSSIL FUEL SUBSIDIES ON RENEWABLE ENERGY DEPLOYMENT[16]

3.1 Introduction

Global energy systems are currently facing major challenges. Population growth and accelerated urbanization entail that the rapid increase of the demand for electricity and other forms of energy will continue, particularly in developing and emerging countries. Moreover, hundreds of millions of people still have no access to electricity and other basic energy services (see Part II). Making modern forms of energy available to reduce poverty and support economic development requires large-scale, reliable and affordable power supply for households and businesses, amongst others. At the same time, minimizing the environmental consequences of increased energy supply in the long term and meeting the ambitious climate mitigation goals established in Paris in December 2015 requires a quick transition away from fossil fuels. In this context, the increased use of renewable energy becomes ever more relevant (Bradshaw, 2014; Stadelmann & Castro, 2014).

Renewable energy generation has grown impressively in the past decade.[17] In 2014, renewables accounted for 85 per cent of the global increase in total power generation (IEA, 2015b). However, non-conventional renewables (i.e., all renewables except hydro power) still accounted for only 6 % of global electricity production in 2014 (REN21, 2015).

In the academic debate on how to increase the share of renewable energy, fossil fuel subsidies are an often neglected factor. However, such subsidies result in price distortions that must be expected to affect the markets for renewables. It is therefore critical to consider fossil fuel

[16] This chapter is based on the following article: Zahno, Martina & Paula Castro (2017) Renewable energy deployment at the interplay between support policies and fossil fuel subsidies. In: Stefan E. Weishaar, Larry Kreiser, Janet E. Milne, Hope Ashiabor & Michael Mehling (eds) The green market transition: Carbon taxes, energy subsidies and smart instrument mixes. Critical issues in environmental taxation volume 19. Cheltenham, UK: Edward Elgar Publishing, 97–112.

Contributions to the article:

Martina Zahno: Conceptualization, data curation, formal analysis, writing – original draft, writing – review and editing.

Paula Castro: Conceptualization, formal analysis, writing – original draft, writing – review and editing.

The chapter at hand is more comprehensive than the article, discussing the theoretical arguments, the data used, the rationale for the statistical methods applied and the results in more detail. In particular, the author of this dissertation provides an own methodological elaboration to illustrate the statistical models employed and, based on this, performs a somewhat different statistical estimation than in the published article.

[17] Note that this study was conducted in 2016, with data available until 2013.

subsidies as part of the relevant policy mix when assessing the effectiveness of renewable energy support schemes.

Using panel data from 155 countries between 2003 and 2013, in this study we provide the first systematic, cross-country evidence that fossil fuel subsidies are highly likely to present a significant barrier to the deployment of renewable energy, even in the presence of policies that also subsidize or otherwise support renewables.

We focus on the generation of electricity from non-conventional renewable energy sources. We intentionally exclude large hydropower from the analysis, since investment decisions regarding large hydro facilities follow a very different rationale than investment in other renewables[18] and can be considered a traditional and competitive electricity source already.

The remainder of this chapter is structured as follows: Section 3.2 summarizes insights from economic theory and empirics regarding the impact of fossil fuel subsidies. The data and descriptive statistics are presented in Section 3.3, followed by a panel regression model of the determinants of renewable electricity production, with a special focus on the effect of fossil fuel subsidies and policies to support renewables in Section 3.4. We discuss our findings in 3.5. Section 3.6 concludes.

3.2 Undesirable effects of fossil fuel subsidies: insights from economic theory

Chapter 2 already demonstrated that many governments heavily subsidize fossil fuel based energy production or prices and that these subsidies lead to distortions of resource allocation, reduce total welfare and have a negative impact on the environment.

Regarding the specific impact on renewable energy deployment, straightforward economic rationale predicts that subsidizing fossil fuels – a close substitute of renewables – leads to reduced demand for and lower production of energy from renewables. The focus of this study is on the proposed consequences for the case of electric power. Direct effects are expected where subsidized oil, natural gas and coal are used as input in power utilities. Any price reduction of the fossil alternative will reduce the optimal quantity of energy produced from renewable sources (Meier, Vagliasindi & Imran, 2015).

Beyond this direct competition effect, more indirect effects are likely. The position of fossil fuels in the power supply system could further be reinforced by an 'incumbency advantage' created by fuel subsidies. For instance – given that returns to scale are usually increasing in the sector – a slowdown of renewables deployment may lead to a decline in learning rates and the associated cost reductions. Moreover, fossil fuel subsidies may drain financial resources away from investments in low carbon technology and infrastructure, since their presence impairs the conditions for investments in renewable alternatives compared to fossil-fuel-based technologies (IEA, 2014: 324 ff.; Kitson & Bridle, 2014; Whitley, 2013).

Strong fluctuations in global oil, coal and natural gas prices may reinforce or weaken the relevance of fuel subsidies for renewable energy production. Yet, fossil fuel subsidies arise due

[18] Large hydropower is for instance frequently financed by large multilateral loans and has very long planning periods.

to a public policy – their intended effect in many countries is to increase the production and consumption of such fuels – and are often provided over long periods. Long-term subsidy schemes hence decrease electricity input prices and consumer end prices on a more constant base than short- and middle-term deviations of international fuel prices do. Thus, fossil fuel subsidies more steadily undermine the investment case for low-carbon energy.

More importantly, investment in renewable electricity capacities relies on subsidies or other support schemes to ensure market entry. Despite falling technology costs, more than 80 % of the power generation capacity from renewables (excluding hydropower) was not competitive yet in 2014 without financial support (IEA, 2015b: 379). For this reason, lower prices for other fuels used in power generation may increase the costs of subsidy schemes for renewables.

IEA experts consider a major decline of policy support for renewable energies in the electricity sector due to lower oil prices unlikely, not least because long-term goals like diversifying the energy supply and increasing low-emission power generation to achieve climate mitigation targets remain in place (IEA, 2015b: 182–183). Nevertheless, evidence from selected countries suggests that government expenditures in fossil fuel subsidies may crowd out public support for renewable technologies directly (Meier, Vagliasindi & Imran, 2015). Persistent crowding out effects on renewable energy support schemes are hence likely in the case of fuel subsidies.

Based on the literature and general theory discussed above, we expect fossil fuel subsidies to matter for the deployment of renewables, beyond the effect of domestic support schemes for renewable energy. In particular, we conclude that fuel subsidies should negatively affect the share of renewable electricity.

Empirically, only a few studies address the potentially negative effect of fossil fuel subsidies on renewables. Case studies in Middle-Eastern and North African countries illustrate how the relative cost advantage of wind and solar technologies due to favorable climatic conditions is thwarted by fossil fuel subsidies (Bridle, Kiston & Wooders, 2014). Schmidt, Born & Schneider (2012) show that the cost differential between renewable energy and conventional technologies varies largely across specific country-technology combinations, so that fossil fuel subsidies have a leverage effect if there is a relatively small cost differential between renewables and the unsubsidized baseline.

However, to our knowledge, so far no large cross-country empirical evidence exists on the potentially adverse effect of fossil fuel subsidies on renewable energy deployment. In this chapter, we thus add a macro perspective to the existing (comparative) case studies, by examining the hypothesis that higher levels of fossil fuel subsidies go along with a lower contribution of renewables to power generation, even after major determinants of renewable energy generation are controlled for.

In the following empirical part, we will first present the data on our main variables and explore the outcome variable (share of renewable electricity) and its relation to fossil fuel subsidies across countries descriptively before we move on to multivariate regressions.

3.3 Data and descriptive analysis[19]

3.3.1 Fossil fuel subsidies

The systematic collection of data on the extent and volume of subsidies on fossil fuels presents a challenge that has only recently been taken up. As discussed in Chapter 2.1, the organizations concerned with the measurement of subsidies apply different approaches, with correspondingly divergent estimation results.

For the analysis at hand, we use the IMF's country-level subsidy estimates, (Coady et al., 2015; IMF, 2015). While data on the extent and volume of fossil fuel subsidies is generally very incomplete – e.g., regarding support for fuel extraction and refining – this dataset contains the most comprehensive and consistent estimations available.

We focus on consumer subsidies for gasoline, diesel, coal and natural gas, for both households and firms (like electric utilities or industry). The IMF dataset further contains complementary data on production subsidies for OECD countries. However, given that the data on producer subsidies is incomplete across the whole country sample, we decided to exclude them from our analysis. Their size (for those countries with complete data) is comparatively small compared to the consumer subsidies though, so we do not expect this omission to be too problematic. In addition, by excluding them, we err by being more conservative. If we nonetheless find a negative effect of the consumer fossil fuel subsidies, then it means that the true effect, including the producer subsidies, must be even larger.

Consumer subsidies are estimated using the price gap approach (see 2.1), which compares end-user prices with some reference price. The total value of fossil-fuel subsidies for a given country corresponds to the aggregated size of the price gap for each fuel in each sector, multiplied by the volume consumed (IEA, 2014: 318–320). The reference price according to the IMF estimations is given by the full cost of supply, i.e., "the opportunity cost to a country of supplying the energy product to consumers". For internationally traded products, this cost is given by their international price adjusted for transport and distribution costs. For non-traded goods, the supply cost is the domestic cost of production evaluated at efficient prices (Coady et al. 2015: 8).

We use the IMF's pre-tax subsidy estimates, which do not include the negative external costs from the combustion of fossil fuels. Overall, the data used in this study are therefore conservative estimates of actual subsidies (similar to those of the IEA, see 2.1), implying that we might underestimate their actual effects. Subsidies are expressed in U.S. dollars per capita.

3.3.2 Share of electricity from non-conventional renewables

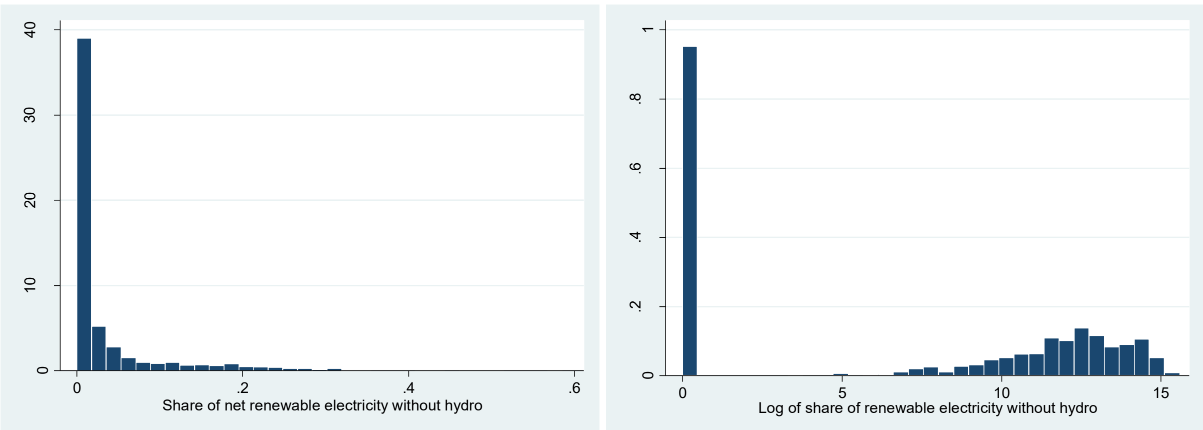
Our dependent variable is the share of net electric power generated from non-conventional renewables including geothermal, solar, tide and wave, wind, biomass and renewable waste. As we intentionally exclude hydropower from our analysis, our approach deviates from other

[19] Data and code are available from the author on request.

studies of renewable energy growth determinants, e.g., the one by Aguirre & Ibikunle (2014), which is based on a measure that includes hydropower.

Data is obtained from the US Energy Information Administration (EIA, 2016), whereby missing values for 2013 are imputed using IEA (2016b). The resulting dependent variable is censored at zero and has a large proportion of zeros, since electricity production from renewable energy sources apart from large hydro has not been prevalent in many countries – particularly developing and emerging ones – until very recently (see Figure 1 and Figure 2). Figure 3 displays the development of renewable energy contribution between 2003 and 2013 for different income-groups of countries. Modern renewable electricity were not yet widespread in most countries. During the observation period, its share has only surpassed 30 % in Denmark, Germany and Nicaragua. The clearest upward tendency during the period under study can be recognized among the advanced economies, but renewables were also on the rise in emerging countries. In particular, in recent years (not covered in this study), Asia has experienced a strong expansion of wind and solar energy, fostered by high ambitions in China and India and bioenergy and wind were quickly expanding in Latin America and the Caribbean (IEA et al., 2019). Across low-income countries, the development has been ambiguous but with a strong upward trend starting in 2012. Nonetheless, non-conventional renewables are still non-existent until 2013 in 37 out of the 57 low-income countries included in the sample.

Figure 1 Distribution of the dependent variable (share of electricity from renewables) Original data and after log-linear transformation



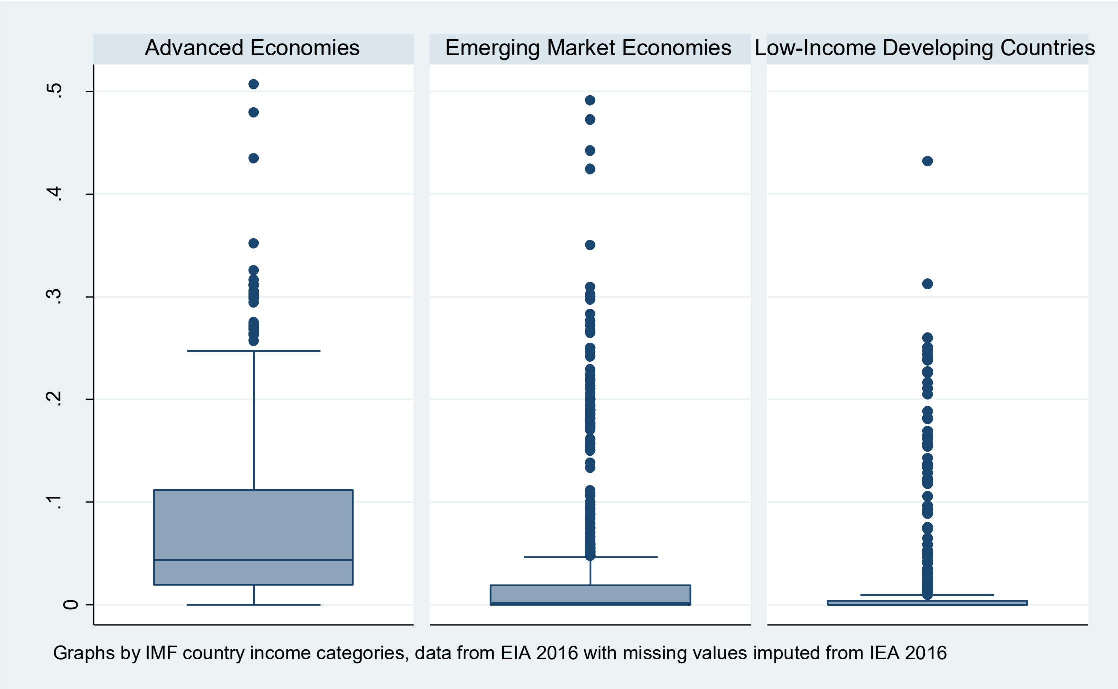
Share of renewable electricity (without hydro)

Share of renewable electricity (without hydro, after log-linear transformation)[20]

Source: International Energy Statistics data from EIA (2016).

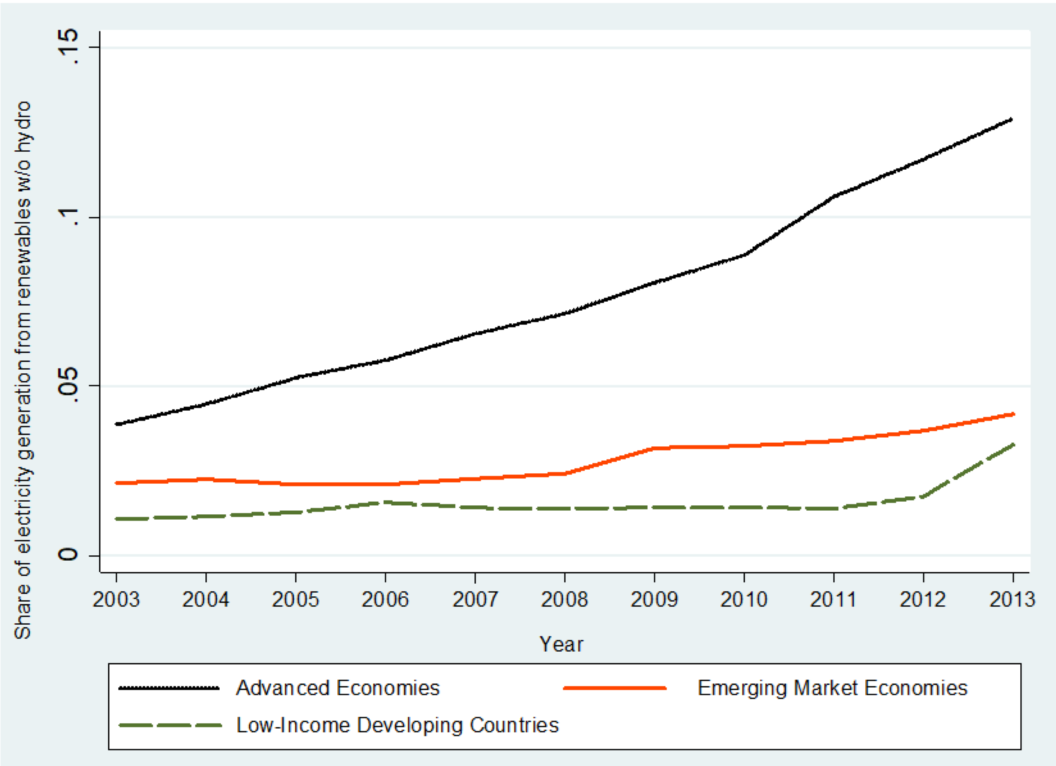
[20] Missings from log(0) adjusted to be zero.

Figure 2 Average share of renewable electricity by income groups (boxplots)



Source: International Energy Statistics data from EIA (2016), data on country income categories from IMF (2015).

Figure 3 Time series for average renewable shares, by country income categories

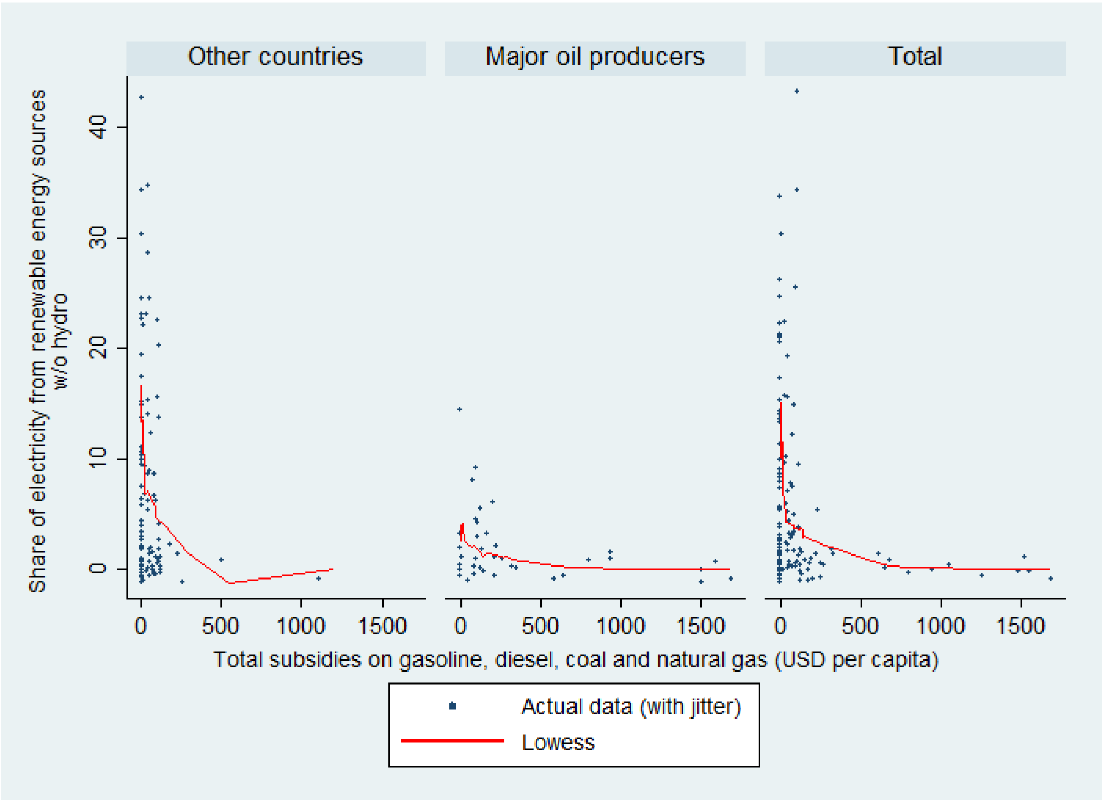


Source: International Energy Statistics data from EIA (2016), data on country income categories from IMF (2015)

3.3.3 Bivariate relationship between fossil fuel subsidies and renewable electricity share

First insights on the potential relationship between the share of renewables and fossil fuel subsidization can be gained from plotting the two variables. Figure 4 displays the plotted pairs of the two variables' values across countries for the year 2013 (with jitter)[21] and a locally weighted scatterplot smoothing.[22] Data on Denmark as top oil producer with zero official fossil fuel subsidies and a very high share (48 %) of renewables is excluded for this graph to ensure a single outlier does not drive results. Across all observations, the data broadly supports the hypothesis that higher fuel subsidies tend to go along with lower shares of renewable electricity. A linear relationship is not recognizable. It can however be stated that the vast majority of countries with high fossil fuel subsidies have very low shares of renewables in their power mix (lower than 5 per cent). At the same time, virtually all countries with a significant contribution of renewables do not subsidize fossil fuels or only marginally.

Figure 4 Share of electricity from renewables and fossil fuel subsidies in 2013



Data for 131 countries in 2013. Graphs by dummy indicating country is among top 30 oil producers globally. *Sources*: Energy Statistics data from EIA (2016), data on subsidies from IMF (2015) and data on population from World Development Indicators (World Bank, 2016), based on data from the IEA, the OECD and the World Bank.

[21] *Jitter* is an option in Stata's *graph twoway scatter* command. It adds spherical random noise to the observations before producing the scatterplot, and by doing so, provides a better visual sense of how many observations relate to each pair of the two variables' values. For more information, see https://www.stata.com/manuals/g-2graphtwowayscatter.pdf.

[22] Stata's *lowess* command carries out a locally weighted regression of Y (percent of electricity from renewables) on X (FFS) and displays the graph. For more information, see https://www.stata.com/manuals/rlowess.pdf.

Figure 4 further shows separate plots for the 30 top oil-producing countries globally as compared to other countries, illustrating how the subsidization of fossil fuels is particularly prevalent in major oil producing countries. Limiting the group of oil producers to OPEC countries would indeed leave us with a share of renewables that is close to zero (not shown here). However, including all 30 top oil-producing countries shows that there is substantial variation in the degree of subsidization as well as renewables participation even within this group.

Alternative plots using data from emerging and developing countries, as well as varying the threshold for the number of top oil producers shows comparable results, indicating that the high shares of renewables in advanced economies do not drive the relationship.

3.4 Multivariate regression analysis

While the bivariate graphs suggest a negative relationship between fossil fuel subsidies and the share of renewable electricity, in this section this hypothesis is tested rigorously. We set up a full panel regression model on the determinants of electricity generation from renewables.

Apart from fossil fuel subsidies, a special focus lies on the role of renewable electricity support policies. As explained above, in most cases the installation of modern renewable electricity generation capacities still relies on financial support. We are thus interested in how such financial support affects the deployment of renewable electricity after accounting for the hypothesized detrimental effect of fossil fuel subsidies. Given that there are no data on the actual magnitude of financial incentives for renewables, we proxy such support through a count variable for a range of country-level policies providing financial support to grid-based renewable electricity production, including feed-in tariffs, other financial incentives such as tax exemptions or reductions, public investments and renewable energy tenders. We exclude softer support measures, such as framework policies for renewables or renewable energy targets from the regressions shown here, as we do not expect them to be that relevant. However, robustness tests with a variable that counted all existing support policies did not alter our results significantly. Data from Stadelmann & Castro (2014) serve as a basis and are completed for advanced economies and updated using data from REN21 (2015) and the Global Renewable Energy policies and measures database (IEA & IRENA, 2016).

3.4.1 Estimation method

Our descriptive analysis of the data revealed that while the contribution of non-conventional renewables to electricity supply varies enormously between countries, the change within countries over time is very small for most countries. Hence, our data – covering a relatively short time period from 2003 to 2013 – cannot reflect the slow transition towards renewable energy well. Consequently, the role of fuel subsidies is analyzed with a focus on exploring the variation between countries.

Apart from addressing the particular structure of the dependent variable, we have to account for clustering of the observations on the country level. Random-effects models allow us to model several important covariates of interest that are time-invariant or very sluggish – such as the potential for renewable energy production. However, these models rely on the assumption that the random effects are uncorrelated with the observed covariates. If this condition is not met, e.g., because unobserved heterogeneity at the cluster (country) level cannot be controlled for, the estimated model coefficients are biased. Fixed-effects models that treat all unobserved effects on the cluster level as fixed provide consistent estimates of time-variant covariates, despite unobserved heterogeneity at the cluster level. Yet, since fixed-effects model estimation uses only within-country variation in the explanatory and dependent variables, while most of the variation in our variables of interests is across countries, we cannot rely on fixed effects models to control for this potential source of bias. Moreover, along the lines of Bell & Jones (2015), we believe that it is profoundly important to our research question to understand and model the role of country context explicitly.

As a compromise, we opt for a *hybrid model* that separates between- and within-cluster effects for the time-variant covariates. The general formulation for the hybrid model by Allison (2009) is given by:

$$Y_{it} = \beta_0 + \beta_1(x_{it} - \bar{x}_i) + \beta_2 c_i + \beta_3 \bar{x}_i + \mu_i + \varepsilon_{it}$$

x_{it} is a variable that varies between and within countries, and c_i is a variable that varies only between countries. μ_i is the between-country error and the random intercept, and ε_{it} is the between and within error. Country-specific means of x_{it} ($\bar{x}_i$) and deviation scores ($[x_{it} - \bar{x}_i]$, also referred to as group mean centering), are generated before fitting the hybrid model with panel random-effects estimation (including both the cluster specific mean and the deviation from the cluster-specific mean in the model). β_1 corresponds to the within-country estimate of time-varying variables and β_3 estimates their between-cluster effect (Schunck & Perales, 2017). The approach pursued in this model is not new. The correlated random effects model which was first proposed by Mundlak (1978) is mathematically equivalent to the hybrid model (Wooldridge, 2010).[23] In linear models, both estimation strategies yield unbiased estimates of the within-effects for time-varying variables (in fact, estimates for these variables are identical to those from a fixed-effect model in linear models), yet they allow inclusion of time-invariant variables (Allison, 2009; Mundlak, 1978; Schunck, 2013).

Due to strong autocorrelation in the dependent variable, we include year fixed effects that should account for broad trends such as technological change and the associated cost reductions as well as international fuel prices or global economic developments. Alternative panel regressions, where we estimate population-averaged effects and apply first-order autoregressive error terms do not substantively alter our results (not shown).

Different estimation methods may be applied to account for the censored data structure and the large proportion of zeros in the dependent variable. Due to non-normality of the data,

[23] Yet it includes the undemeaned form of the time-varying variables x_{it} and as a consequence, the estimated effect of $\bar{x}_i$ is not the between effect, but the difference between β_1 and β_3. See also Schunck (2013).

even after a log-linear transformation, a panel Tobit model cannot be applied. We therefore apply a two-part model.[24] Two-part models are a common alternative to panel Tobit models for modeling censored data such as ours and further allow for the possibility that the zero and positive values are generated by different mechanisms, that is, affected by different sets of variables or affected differently by the same variables.

In our case, for the first part, we apply probit models to predict the likelihood that country i generates a positive amount of electricity from non-conventional renewables in year t. For the second part, containing positive values for the dependent variable y, we transform y to logs and estimate the relationships between y and the other variables of interest in a linear panel regression model. For both parts, within and between effects are decomposed as outlined above, for those variables that vary sufficiently within clusters and for which within-cluster effects are statistically different from the between-cluster effects. We do so using Stata's `xthybrid` command (Schunck & Perales, 2017) that allows testing the random-effects assumption (implying that the between-cluster effects are statistically not different from the within-cluster effects) for individual regressors. Appendix A provides further explanations on the estimation strategy and compares an exemplary version of the hybrid model used in this chapter (see 3.5) with alternative panel data models commonly applied in the context of unobserved effects.

3.4.2 Determinants of renewable electricity generation

In addition to analyzing the effect of fossil fuel subsidies and renewable electricity support policies, we control for further variables that the existing literature on the determinants of renewable energy production or consumption has found to be relevant (Aguirre & Ibikunle, 2014; Marques, Fuinhas & Pires Manso, 2010; Popp, Hascic & Medhi, 2011; Sadorsky, 2009a, 2009b).

High-income countries have a better capacity to invest in renewable electricity. The environmental Kuznets curve theory further suggests that while in the early stages of economic development, material well-being is valued more than environmental amenities, citizens pay greater attention to the environment once a sufficiently high standard of living is attained (Arrow et al., 1995). We hence add a control for the log of GDP per capita in constant purchasing power parity terms (constant 2011 international dollar). The data is obtained from the World Development Indicators (WDI) (World Bank 2016). The argument above however holds only to the extent to which policies reflect people's preferences. In democracies, the population's preferences (including those for a clean environment) are better represented. More generally, democratic regimes are more responsive to the demand for public goods than authoritarian

[24] In preliminary regressions, we also tested a pooled Heckman selection model. However, in most specifications of this model the results showed that, the selection and the outcome equations can be assumed to be independent. Furthermore, it was difficult to find a credible exclusion restriction that is necessary to make the Heckman estimation robust. We therefore turned to the simpler two-part models. This, in addition, allowed us to exploit the panel structure of the data.

regimes (Bueno De Mesquita et al., 1999). Based on this rationale we control for the level of democracy using the Freedom House 'polity' indicator (Freedom House, 2015).[25]

The cost of renewable electricity depends crucially on the local availability of the corresponding resources. We thus include a variable that aggregates the country-level technical potential for energy production from different renewables (including solar, geothermal, on- and offshore wind, and sugar crops and livestock manure as proxies for biomass potential), estimated by Buys et al. (2007, 2009).[26]

We additionally account for the energy consumption of a country – which should affect demand for renewables – by including the logged total primary energy consumption, with data obtained from the IEA (2016b).

Electricity supply from renewables is also related to energy security concerns. The literature suggests that the deployment of renewables is incentivized by the aim to substitute energy imports with locally produced energy (Gan, Eskeland & Kolshus, 2007). Following Marques, Fuinhas & Pires Manso (2010), we calculate the dependence on energy imports by taking the difference between countries' total energy exports and total energy imports and expressing it as a share of their total energy consumption. The data is from EIA (2016).

Environmental concerns can be expected to simultaneously affect the share of renewables and fossil fuel subsidies. As a measure for countries' efforts in promoting environmental quality we use an adapted version of the Environmental Performance Index (Hsu et al., 2016; YCELP, CIESIN & WEF). We excluded two categories of components from the composite index. First, measures of environmental stresses on human health, as they are strongly poverty related (e.g., access to drinking water and sanitation or child mortality) and second, climate policy indicators such as CO_2 emission intensity, which would be good controls for a country's level of responsibility towards climate change, but can cause a problem of reverse causality. That is, while we expect that countries with higher emissions should have a higher incentive to deploy renewables, at the same time increasing renewables reduces emissions. Robustness checks with the complete Environmental Performance Index or with a dummy indicating time of Kyoto Protocol ratification as a more direct control for concerns regarding climate change did not change our findings (not shown).

The presence of oil and gas resources is another relevant factor. Major oil producers tend to support the domestic oil industry and hold domestic fuel prices low. This structural bias can be expected to have a negative impact on the support of renewables deployment. However from a long-term perspective, volatile global oil prices might also incentivize investments into

[25] Data retrieved from the Quality of Government Dataset, by Teorell et al. (2016). In addition, government effectiveness is an important precondition for any investments in a country. We thus tried controlling for government effectiveness using data from the Worldwide Governance Indicators in robustness checks, but its effect is unclear given the strong correlation with income and democracy. See Kaufmann, Kraay & Mastruzzi (2011).

[26] The World Bank paper also included estimates for hydro, jatropha and switchgrass ethanol potential. As we exclude hydro power generation from our study, and as jatropha and switchgrass are used to produce biofuels destined mainly for transport, we do not include these estimates in our operationalization of renewable energy potential. However, robustness tests including jatropha and switchgrass potential did not affect our results significantly. Also, robustness checks in which we controlled for the different sources of renewable potential in separate variables did not affect our results substantially.

alternative domestic energy supply in order to free oil resources for exports.[27] Major oil producing countries also generally face comparatively lower financial constraints with regards to support for new renewable energy infrastructure. Hence, effects in both directions are plausible. We thus include a dummy for members of the Organization of the Petroleum Exporting Countries (OPEC) as an indicator for oil-producing countries in our model. Since the net import variable is likely to reflect to some extent the oil and gas resources of a country, we will also present models that do not include the net import variable in order to address multicollinearity issues.

3.5 Results

Table 1 and Table 2 present the results of our main two-part regressions for different model specifications in the binary and the positive part respectively. Overlined variables denote the country-specific means with their coefficients indicating between-country effects (see 3.4.1.).

In terms of the probability that a country produces any amount of electricity from renewable energies at all, our estimates from the basic model in Table 1, Column 1, do not indicate a statistically significant relation to fossil fuel subsidies.[28] In contrast, the coefficients for renewable energy support policies are significantly positive in the between part of the regression. The average partial effect (APE) shown along with the coefficient suggests that every thing else being equal, countries that had on average one more financial support measure in place during the observed period were on average about 20 percentage points (pp) more likely to produce some of their electricity from renewable energy sources. Providing financial support to grid-based renewable electricity production through measures like feed-in tariffs, tax exemptions or renewable energy tenders thus seems to be critical for setting the initial stage of producing renewable electricity, even though no significant effects seem to stem from within-country increases in the number of financial support policies over time. The latter holds for the main models presented here, in which we do not take into account the time-lagged effects of support measures, as we consider a relatively immediate effect to be realistic for financial support measures that are announced well in advance and since we preferred not to reduce the size of the already short panel data set. However, estimations of the basic model in Column 1 where support measures are included with a time lag of one to 3 years suggest a statistically significant relationship between support measures and the probability of electricity production from renewables with a 3-year time lag (see Table A 3, Column 3 in Appendix B.) The APE corresponding to the coefficient of RE policies (t-3) is 0.052, suggesting that an additional financial support policy for renewables in country i increases its probability of generating power from renewables by 0.05.

[27] This is apparently the case in a number of countries in the Middle East, one of the few regions where oil is still widely used in the power sector; the sharp fall in oil prices in recent years has led to efforts to reduce domestic oil demand and to replace parts of the fuel-based power generation by renewables according to The Guardian (2016).

[28] Note that due to a lack of alternative comprehensive datasets on the volume of fossil fuel subsidies on the country level (see 2.1), we did not run robustness tests with other fuel subsidy estimates.

The coefficients of the control variables are generally as expected, and, as can be shown when separating effects for all time-varying variables (see Zahno & Castro, 2017: 105), they are observed mainly at the between-country level. Regarding environmental concern, a country scoring on average 10 points higher on the environmental performance index (scale = 0 to 100) than others is 5 pp more likely to produce some of its electricity from renewable energy sources. For the OPEC dummy, we find a highly significant negative effect on countries' likelihood to invest in renewable electricity (decresase by 0.35). This result supports the hypothesis that fuel-based economies are far from a transition towards higher shares of renewables.

Furthermore, a renewable energy potential, which is increased by 10 megatonnes of oil equivalent (corresponding to about twice Switzerland's total power consumption), raises the probability of renewable electricity production on average by 0.01. In contrast, we cannot detect any statistically significant link between the probability of electricity production from renewables and the covariates GDP and democratic institutions in our main model. The non-significant effect of GDP might be explained by the fact that environmental protection strongly correlates with the increasing wealth of countries, which is why the coefficient of the environmental performance index partly reflects the effect of economic prosperity. In alternative estimates, in which we include the ratification of the Kyoto Protocol instead of the environmental performance index to reduce this collinearity, we find significant positive effects of GDP (not shown).[29]

The models in Columns 2 and 3 additionally include primary energy consumption and the dependence on energy imports (i.e., the share of net imports) as further important factors that are likely to affect the demand for renewables. Despite careful variable selection, some of the energy-related predictors deemed important on theoretical grounds are collinear, notably GDP, energy use and fossil fuel subsidies. Net imports are furthermore defined as a share of energy consumption and are hence per definition correlated with the latter. The fact that our dataset is relatively small tends to exacerbate the risk of multicollinearity problems. In order to reduce multicollinearity, and the risks of unstable coefficients that are difficult to interpret that it implies as far as possible, we add the additional, energy-related variables in separate models.

Our results in Column 2 suggest that on average, a 10 % increase in total primary energy consumption is associated with an only slightly higher probability of power generation from renewables (increase of 0.005). This result remains essentially the same when we exclude GDP from the regression in Column 2 (not shown). Somewhat surprisingly, the coefficient of GDP is negative and significant in this specification. Yet, the APE is substantively very small (0.003 increase in predicted probability when increasing GDP per capita by 10 %) and, given the collinearity with energy consumption (Pearson's r=0.57), the unstable results for GDP across specifications (1) to (4) may be a consequence of remaining multicollinearity.

[29] However, the effect is not significant across all specifications. Moreover, these models fail to capture a country's general commitment to environmental protection (and energy transition), which is why we prefer using the models that include the environmental performance index.

Table 1 Regression results for the likelihood to produce electricity from renewables

Model	(1)		(2)		(3)		(4)	
	Coeff	APE	Coeff	APE	Coeff	APE	Coeff	APE
FF subsidies p.c. (log)	-0.011	-0.000	-0.006	-0.000	-0.020	-0.001	0.003	0.000
	(0.153)	(0.005)	(0.203)	(0.004)	(0.137)	(0.005)	(0.199)	(0.004)
$\overline{\text{FF subsidies p.c. (log)}}$	0.174	0.007	0.008	0.000	0.182	0.007	-0.422*	-0.008*
	(0.163)	(0.009)	(0.149)	(0.008)	(0.157)	(0.009)	(0.222)	(0.008)
RE policies	-0.132	-0.005	-0.201	-0.004	-0.117	-0.005	-0.058	-0.001
	(0.358)	(0.011)	(0.514)	(0.011)	(0.352)	(0.011)	(0.583)	(0.010)
$\overline{\text{RE policies}}$	5.572***	0.208***	8.370***	0.169***	5.345***	0.206***	10.089***	0.190***
	(0.598)	(0.055)	(1.390)	(0.056)	(0.659)	(0.054)	(1.863)	(0.055)
Environmental performance	-0.150	-0.006	0.014	0.000	-0.119	-0.005	-0.069	-0.001
	(0.176)	(0.005)	(0.275)	(0.005)	(0.162)	(0.006)	(0.266)	(0.005)
$\overline{\text{Environmental performance}}$	0.125**	0.005**	0.315***	0.006***	0.117***	0.005***	0.172**	0.003**
	(0.053)	(0.004)	(0.065)	(0.003)	(0.043)	(0.003)	(0.072)	(0.003)
Democracy	0.128	0.005	0.519**	0.011**	0.119	0.005	0.601**	0.011**
	(0.182)	(0.008)	(0.218)	(0.008)	(0.190)	(0.009)	(0.306)	(0.008)
Re potential	0.028**	0.001 **	0.013	0.000	0.029***	0.001***	0.009	0.000
	(0.012)	(0.001)	(0.015)	(0.001)	(0.011)	(0.001)	(0.013)	(0.001)
OPEC	-9.409***	-0.351***	-15.360***	-0.311***	-8.379***	-0.322***		
	(2.290)	(0.180)	(2.243)	(0.149)	(2.151)	(0.177)		
GDP p.c.(log)	0.097	0.004	-1.627***	-0.033***	0.179	0.007	-0.862	-0.016
	(0.469)	(0.026)	(0.583)	(0.031)	(0.488)	(0.028)	(0.940)	(0.030)
Energy consumption (log)			2.648***	0.054***			3.003***	0.056***
			(0.490)	(0.028)			(0.670)	(0.026)
Net energy imports share					0.002	0.000		
					(0.002)	(0.000)		
Constant	-7.072	–	1.408	–	-7.330**	–**	-1.391	–
	(4.335)	(–)	(4.789)	(–)	(3.677)	(–)	(8.866)	(–)
Log Likelihood	-153.10		-138.41		-153.44		-142.45	
Observations	1392	1392	1392	1392	1392	1392	1392	1392
Year Dummies	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Standard errors in parentheses. * $p < .1$, ** $p < .05$, *** $p < 0.01$. FF stands for fossil fuels, RE for renewable energy. Number of countries: 155

In Column 3, we find no significant effects for the net imports as a share of total energy consumption. Since oil-dependent economies tend to subsidize fossil fuels much more than others, we also applied a regression without accounting for OPEC membership. The results are shown in Column 4. While our results do not alter substantively, the time-average of fossil fuel subsidies now displays a coefficient which is borderline significant. However, since there is a high risk of omitted variable bias in model (4), this finding is not robust. Like in (2), the results of model (4) further suggest that countries with more democratic political systems tend to be somewhat more likely to have renewables in their powermix; however, the effect is not robust across model specifications in this part of our estimation.

Robustness checks where the year dummies were replaced by international fuel prices or by fuel prices and a year trend (not shown), did not affect our other results substantively. The same is true if we limit the sample to low-income and emerging economies (see Table A 4 in Appendix B). Additionally, we restricted the sample to those countries with the highest variation in subsidies along the time period observed, corresponding to the highest 40^{th}, 50^{th}, 60^{th} or 70^{th} percentiles (see Table A 5 in Appendix B). We used simple pooled probit models in these subsamples to explore whether there is any significant within-country effect of fossil fuel subsidies in the countries in which this is most likely. As a final robustness check, we collapsed our sample into two periods, 2003–07 and 2008–12, and took the means of all variables for each country in those periods (not shown). The rationale behind this is to model the longer-term effects, given the slow rate of change in the dependent variable. In these robustness checks, we find again insignificant effects of fossil fuel subsidies and positive effects of renewable energy support policies on the likelihood that countries invest in renewable electricity.

The results regarding the amount of renewable electricity generated are displayed in Table 2. We separate within- and between-cluster effects for the covariates fossil fuel subsidies, renewable energy support policies, net energy imports and the share of electricity from hydropower, following the procedure outlined above (see also Appendix A). In this case, fuel subsidies are as expected negatively related to the share of renewable electricity when they are compared across countries.

The coefficient of $\overline{\text{FF subsidies p.c.(log)}}$ in Column 1 suggests that a 1 % increase in the time-average of fossil fuel subsidies per capita is associated with a 0.16 % decrease in the share of renewables in total electricity production. A simplified linear extrapolation thus suggests that countries that subsidize fossil fuel consumption 50 % less than others tend to have renewable energy shares that are on average 8 % higher, all other things being equal. Yet again, within countries, increases of fuel subsidies do not appear to be associated with a decrease of renewables in the power mix in a statistically significant way.

Table 2 Regression results for share of electricity from renewable energies

	(1)	(2)	(3)	(4)
FF subsidies p.c.(log)	-0.005	-0.004	-0.004	0.002
	(0.012)	(0.011)	(0.011)	(0.012)
$\overline{\text{FF subsidies p.c.(log)}}$	-0.162***	-0.120**	-0.157***	-0.129**
	(0.054)	(0.057)	(0.054)	(0.055)
RE policies	0.087*	0.086*	0.080*	0.113**
	(0.045)	(0.044)	(0.045)	(0.046)
$\overline{\text{RE policies}}$	0.219	0.457*	0.200	0.494**
	(0.231)	(0.253)	(0.242)	(0.248)
Environmental performance	0.055***	0.051***	0.056***	0.053***
	(0.015)	(0.016)	(0.015)	(0.015)
Democracy	0.134**	0.120**	0.139***	0.135**
	(0.052)	(0.053)	(0.052)	(0.057)
RE potential	0.001	0.002**	0.001	0.000
	(0.001)	(0.001)	(0.001)	(0.001)
OPEC	-1.745	-1.593	-1.701	-1.974*
	(1.077)	(1.098)	(1.075)	(1.066)
GDP p.c.(log)	-0.262	0.018	-0.288	-0.165
	(0.221)	(0.252)	(0.222)	(0.232)
Energy consumption (log)		-0.344**		
		(0.135)		
Net energy imports share			-0.002***	
			(0.001)	
$\overline{\text{Net energy imports share}}$			0.000	
			(0.001)	
Hydro electricity share				-0.014**
				(0.006)
$\overline{\text{Hydro electricity share}}$				0.013*
				(0.008)
Nuclear electricity share				-0.027***
				(0.006)
Constant	8.862***	6.097***	9.051***	7.743***
	(1.654)	(2.031)	(1.659)	(1.781)
Log Likelihood	-1725.746	-1722.783	-1725.113	-1614.823
Observations	862	862	862	816
Number of countries	102	102	102	95
Year Dummies	Yes	Yes	Yes	Yes

Standard errors in parentheses. * $p < .1$, ** $p < .05$, *** $p < 0.01$. Log Likelihood for model comparison. FF stands for fossil fuels, RE for renewable energy.

One might therefore argue that the effect resulting from differences between countries may be partly an artefact of other, unobserved country differences. Due to our estimation strategy, we cannot completely reject this possibility. We assume, however, that the different effects are much more likely to stem from, first, the dominance of between-cluster variation in subsidy levels and, second, from the fact that impacts of varying subsidy levels within a national energy system cannot easily be attributed in terms of time. In particular, subsidy levels are subject to short-term fluctuations, depending on oil price levels in many countries, while actual, long-term price reforms are rare, and often become reversed.

This issue is not apparent for direct renewable energy support measures in this part of the estimation. The significantly positive coefficient of RE policies in Column 1 implies that introducing one additional financial support policy for renewables is associated with an increase of the renewable electricity share by almost 9 %. The coefficient of the time-averaged policy measure also shows a positive association with the outcome variable; however, the effect is unstable across estimation specifications, maybe due to multicollinearity. Alternative estimations where we use random-effects estimators for the policy variable show positive and significant effects of RE policies (see Table A 2 in Appendix A). We are therefore seeing consistent, positive effects of financial support measures for renewable energies. When some electricity is already being produced from renewable energy sources, the effect of additional measures on individual countries' development of renewable energies can be demonstrated, while keeping any cross-country differences constant. In terms of the probability of producing electricity from renewable energy sources at all, however, there is primarily a link to the average level of support over the longer term.

Again, the coefficients for most control variables are as expected. Democratic institutions turn out to be a significant driver of renewables deployment in this development stage (scoring one point higher on the democracy scale (0 to 10) is associated with a 10.3 % increase of the renewable energy share). Our control for OPEC membership is however insignificant, which is not completely surprising because most OPEC members simply do not have any renewable electricity in the time period analyzed.

Just as in the first part of the model, the GDP covariate is not linked in a statistically significant way to electricity generation from renewables. This is at least partly attributable to the collinearity between economic welfare and environmental performance – again a highly significant predictor of the renewable energy share – as further estimations using a dummy for Kyoto protocol ratification instead of the environmental performance indicator reveal (not shown).

Additionally controlling for primary energy consumption or the dependence on energy imports, as displayed in Columns 2 and 3, does not change our main results. The coefficient for energy consumption suggests that a 1 % increase in total energy consumption is associated with a 0.35 % decrease in the share of electricity from renewables. The negative relationship in this stage is not entirely surprising, since a strong increase in energy demand boosts total electricity production and, while power generation from renewables is growing rapidly, the volumes produced during the period under consideration were still comparatively small. With respect to dependence on imported energy, there is a significant, but substantively minor, correlation with the share of electricity from renewable sources (0.2 % decrease associated with an increase in the share of imported energy by 0.01). The greater incentive to invest in renewable electricity production due to increasing energy dependence thus appears to be overridden by other factors, such as the fast growth in overall energy demand.

As additional controls, we tested the share of nuclear and hydropower in the electricity mix (Column 4). Negative effects can be expected, because once built, nuclear and large hydropower plants generate electricity at low marginal costs, thus acting as low-cost competitors to renewables, even though the initial investment costs were high.[30] We find that higher shares of nuclear electricity are significantly negatively related to the share of renewables. For electricity from large hydropower plants, our separate estimations of within- and between-cluster effects suggest that increasing the share of electricity from hydropower is related to a smaller contribution of modern renewables in the same country, while the effects of time-averages are positive. This would suggest that, while overall, countries investing more in large hydropower as a 'traditional' source of renewable energy are also more successful in increasing their power generation from newer technologies like photovoltaic and wind power, within individual countries different fossil-free power generation technologies compete with each other to some extent. The effects are small though.

We ran similar robustness tests as for the binary part. Limiting the sample to low-income and emerging economies leads to very similar findings. The effects of financial support instruments for renewables are even stronger among low-income and emerging countries (Table A 6, Appendix B). These groups of countries had low shares of renewable energies compared to high-income countries in the period under review, whereby support measures in this initial stage probably have an even greater effect.

Restricting the sample to those countries that have more variation in fossil fuel subsidy levels leaves us, obviously, with much smaller samples and a subsidy variable with much stronger within-cluster variation (and less between-cluster variation) as compared to the full sample. The results provide us with some interesting new insights (see Table A 7, Appendix B). We discovered the expected negative coefficient for fossil fuel subsidies when looking at the within-country effects. It seems that when looking at the relevant countries, we do find that within a country, higher subsidies are related to less renewable energy deployment (or vice versa). However, for these subsamples, the more general cross-country tendency that we observed in the general models in Table 2 is reversed: when comparing across the countries with highest variability in fossil fuel subsidization, higher fossil fuel subsidies are related to a higher share of renewables. These results become stronger the higher the chosen threshold for the fossil fuel subsidies differential. It is difficult to determine the mechanisms driving this negative relationship. Yet, it is important to note that the subsamples with very high subsidy variation (ffs_60 and ffs_70) are not only very small, they also differ fundamentally from the

[30] In addition, nuclear and hydro power reduce countries' energy dependency, which is one of the reasons for investing in renewables. Data on the share of nuclear and hydro power from all net power generation stems from the World Bank World Development Indicators.

other observations. While income levels are essentially the same, the share of renewable energies in the relevant subsamples is only about one-half of the average share among the other observations, and the subsidy payments are about fifty (!) times higher. There are also many top oil producers in the restricted samples. Moreover, in the ffs_60 and ffs_70 subsamples, high subsidies are strongly correlated with higher incomes (which is not the case for the excluded observations), and income levels are in turn more strongly related to the share of renewables in the power mix than among the excluded observations. Hence, considering these multicollinearity issues and the small sample sizes, these results must be interpreted with caution. Nevertheless, when running simple panel fixed-effect regressions with the same subsamples to account for the increased within-cluster variation, we find consistently negative and significant links between fossil fuel subsidies and electricity production from renewables (see Table A 8, Appendix B).

Finally, collapsing our dataset into averages for the periods 2003–07 and 2008–12 we also obtain results that generally support our expectations (not shown).

3.6 Conclusions

Using a comprehensive cross-country dataset spanning 10 years, this chapter aimed to empirically test the assertion that fossil fuel subsidies present a barrier to renewable energy deployment and to quantify these effects while taking into account financial support policies for renewables.

Our findings provide empirical evidence that, across countries, higher subsidies for fossil fuels are linked to a lower share of electricity from renewable energies (without large hydropower). For cases with some electricity already being produced from renewables, our estimates suggest that, across countries, subsidizing fossil fuels per capita by 1 % more is associated with a 0.16 % lower share of renewables in the power mix on average. A simplified linear extrapolation thus suggests that countries with 50 % lower per capita subsidies than others have on average an 8 % higher share of renewables in their electricity mix than the latter, holding all other factors equal.

That said, the results from our main models do not provide evidence for a direct adverse effect of fuel subsidy increases within individual countries. This is presumably because subsidies vary greatly between countries, while fluctuations within countries are limited and often lack a clear pattern. Whether between-cluster effects, like the ones identified in our analysis, can be meaningfully interpreted in panel data analyses is a matter of debate among scientists. Yet, they provide the first cross-country evidence of the adverse consequences of fossil fuel subsidization on renewable electricity provision. Moreover, our additional analysis focusing on countries whose subsidies have fluctuated considerably over the period under consideration show that in this context, significant effects from subsidy reform within individual countries are possible.

Regarding subsidies and other financial support measures for renewables, we find consistent, positive effects on renewable energy deployment. By simply considering the number of financial support instruments in force, we can conclude that introducing an additional measure in a given country is on average associated with an almost 9 % higher share of electricity from renewable energy sources, given that some electricity is already produced from renewables.

Stringent environmental policy and democratic institutions are further key factors for which we show significant and substantially relevant positive links to the further deployment of renewable energies from a global perspective.

The role of support provided to fossil fuels and to renewables, but also of further relevant factors, appears to be somewhat different when it comes to the initial stage of renewable energy deployment, which we analyzed separately in this chapter. We found that the likelihood that a country produces any electricity from renewables does not seem to be related to fossil fuel subsidies. The fact that the adverse effect of subsidies on fossil fuels is significant only in terms of relative production volumes is not necessarily surprising. For it can be assumed that the cost ratio of renewable and fossil energies is more likely to be reflected in the relative generation volume of renewable energies than in the mere probability that any photovoltaic or wind power plant is in operation at all.

Rather, other country-level factors are found to be relevant at this initial stage, namely the reliance of a country's economy on oil production, its potential for renewables compared to other countries, its financial support policies for the deployment of renewables, and its general environmental performance. Indeed, financial support to grid-based renewable electricity production through measures like feed-in tariffs, tax exemptions or renewable energy tenders seems to be critical as it reduces financing costs. Our results suggest that countries that had, on average, one more financial support measure in place during the observed period were, on average, much more likely to generate some part of their electricity from renewable energy sources (probability increased by 0.2). Additional estimations with lagged policy variables further indicate significant effects within countries. Similar to subsidies for fossil fuels, country-level differences in support policies for renewables dominate differences in individual countries.

While our study provides the first cross-country evidence of the adverse consequences of fossil fuel subsidization on renewable electricity provision, our results do not allow us to identify a causal effect within countries. Further research is therefore needed to strengthen the empirical evidence on how the magnitude of fuel subsidies is related to the share of renewables in the energy mix and to provide insights into causal mechanisms on the country level, taking into account the specific technological and policy environment. Matsuo and Schmidt (2017), for instance, take an interesting approach by examining the carbon mitigation potential and costs when combining subsidy reform with renewable energy deployment policy in a set of illustrative country cases. Case studies could further add evidence by tracing the role of subsidy policies in decision-making processes on energy-related issues in individual countries. Another way to improve evidence on the impacts of fuel subsidies could consist of in-depth analyses of one selected product such as natural gas or diesel with a focus on regions where these subsidies are most prevalent.

A further limitation of our research is that it uses data on estimated volumes of fuel subsidies that is incomplete and subject to great uncertainty. The unsatisfactory data quality is in part attributable to the lack of an internationally recognized definition of fossil fuel subsidies. There are, however, efforts at the international level to address this concern, notably in the context of peer review and self-review processes of G20 countries.

In future, data on electricity production from renewable energies will also have a structure that is better suited for aggregated analyses, as due to the rapid development we can currently observe in the sector, there will be a much higher share of cases that generate some electricity from renewables.

Hence, in order to attain improved evidence on the adverse impacts of fuel subsidies on the aggregate level, it would certainly be instructive to carry out an analysis similar to the study presented here in the future, with a longer panel and improved data.

Despite the limitations outlined here, we can conclude as a policy-relevant insight from our research that efforts to reform fossil fuel subsidies and redirect public expenditures to investments in non-conventional renewable technologies can be expected to benefit the further dissemination of renewable energy.

Overall, the evidence presented in this first part of the thesis underpins the need to reduce or eliminate subsidies on fossil fuels as a means to mitigate climate change. Taking action to combat climate change is part of the 2030 Agenda for Sustainable Development (SDG 13). Closely linked to SDG 13, SDG 12 aims to ensure more sustainable consumption and production. One of the targets it includes to achieve more sustainability is the reform of inefficient fossil fuel subsidies (SDG target 12.c). As described above, the removal of subsidies on fossil fuels contributes to multiple further objectives of sustainable development, including the protection of life on land (SDG 15), economic growth (SDG 8) and public health (SDG 3), through lower air pollution. Redirecting resources spent on fossil fuels towards education or social protection provides further benefits to vulnerable groups.

It is widely recognized that when reforming fossil fuel subsidies, the social impact of these reforms should be minimized, with particular emphasis on protecting the most vulnerable groups. One of the main issues to be considered in this context is access to modern energy services, which are essential for meeting basic human needs and for economic development. Subsidies on fossil fuels are generally considered a very inefficient instrument for improving access to modern energy for the poor, leading above all to excessive consumption of fossil energy by those who can afford it even without subsidies (see Chapter 2). At the same time, it is important to distinguish different energy sources as well as between specific target groups, for some of which subsidies may be justified in certain situations.

A relevant example in this context is liquefied petroleum gas (LPG) for cooking, as my research on residential energy access in the second part of this thesis suggests.

PART II
ACCESS TO CLEAN HOUSEHOLD ENERGY FOR COOKING

Preface to Part II

Modern energy services are crucial for reliable and efficient lighting, heating and cooking in households, for healthcare and transport, to power industrial processes, and for the provision of clean water and sanitation. Human well-being and economic development hence fundamentally rely on access to modern energy services. What exactly *access to modern energy services* comprises is not laid down in an internationally recognized definition. There is, however, broad agreement on some key components including, first, access for households to a minimum amount of electricity and to safer and more sustainable fuels and stoves for cooking and heating, and second, access to modern energy for public services and productive economic activity (IEA, 2019a). Yet it is worth noting, that progress towards achieving SDG 7.1, universal access to affordable, reliable and modern energy services by 2030, is only evaluated at the household level, based on the share of the population that has access to electrificity and relies primarily on clean[31] technologies and fuels for cooking (IEA, 2019a; IEA et al., 2019). In this doctoral thesis, too, the work on energy access is focussing on basic energy services in the household sector.

Especially since the adoption of the SDGs in 2015, energy access deficits (also called energy poverty) have received more attention at the international level and efforts to tackle the issue have increased. The technologies employed for addressing energy poverty in the residential sector include, among others, extensions of the electricity grid, mini- or micro-grids, off-grid systems as well as energy-efficient and cleaner cookstoves and fuels. These technologies are being promoted through a range of business and financing models (see e.g., Sovacool, 2014).

Marked progress has been made since 2010 in expanding electricity access, as the world population without access to electricity has been reduced from 1.2 billion in 2010 to around 840 million in 2017 (IEA et al., 2019). Falling cost of decentralized renewables and the availability of low-cost, energy-efficient appliances, together with new business models using mobile-enabled platforms made a number of solutions available to serve people with no access to electricity. Meanwhile, about 2.9 billion people still lack access to clean cooking technologies or fuels. This number has hardly decreased since 2010 despite some progress in terms of increased access to clean fuels and electricity (for cooking), because strong population growth simultaneously increased the absolute number of persons relying on biomass (IEA et al., 2019).

The international community is hence very far from the goal of universal access to energy. Great challenges remain, in particular in the area of residential energy for cooking, where multiple obstacles, such as affordability, lack of awareness or limited market development opportunities hinder progress in achieving access to clean cooking solutions at scale.

A growing scientific literature contributes to a better understanding of energy poverty and its consequences and evaluates options to address it. Yet we still have a limited understanding

[31] Reiterating from the introduction (Chapter 1), and in line with the major organizations assessing progress towards SDG 7, in this thesis I consider clean cooking facilities to be modern fuels and technologies that minimize emissions that are harmful to health and the environment. These include natural gas, LPG, electricity and biogas or improved biomass stoves with much higher efficiency and significantly lower emissions than traditional stoves or open fires. See IEA et al. (2019).

of which technologies, business- and financing models work most effectively and of how different socio-economic and external factors influence household consumption choices. The second part of this dissertation thus seeks to contribute to our knowledge on interventions to improve basic energy access. Hereby it takes a specific focus on clean household energy for cooking.

It starts by introducing the reader to clean cooking as a policy issue in development cooperation, based on literature from multiple research disciplines, including public health, climate- and environmental science and development economics as well as from policy documents in two context-chapters, as follows. Chapter 4 introduces to the environmental and public health problems associated with traditional biomass use and reviews the most promoted cleaner and more efficient alternatives in terms of their effectiveness according to current scientific evidence. Advantages of alternative cooking stoves and fuels only materialize if the concerned households use these alternatives on a regular basis. The chapter thus further summarizes the existing knowledge on what drives or impedes the widespread adoption and use of clean and efficient cooking facilities. While this review focuses on understanding how households are making the transition to clean cooking energy, the subsequent Chapter 5 provides a complementary account by examining the efforts made by governments and the international (development) community to accelerate this process. Based on these insights, I identify several aspects of residential energy transitions for which we still have an insufficient understanding in social science research, at both levels -- housholds' demand behaviour and donor strategies. In Chapters 6 and 7, I present the scientific work that I carried out on these questions – partly in collaboration with other researchers.

4 SOLID FUEL USE AND HOUSEHOLD ENERGY TRANSITIONS

By 2017, close to 3 billion people globally relied on solid fuels, namely traditional biofuels such as wood, animal dung or crop residues, but also coal (IEA, 2019b). In many low-income countries, traditional biomass is the most important source of household energy, and in the poorest countries, it even dominates the overall energy supply.

The fuels are typically burned in open fires and small simple cooking devices that are inefficient and often unvented. The incomplete combustion causes high levels of fine particulate matter and other pollutants, which are responsible for one of the largest global public health burden. The World Health Organization (WHO) estimates that household air pollution (HAP) associated with solid biofuel combustion leads to almost 4 million premature deaths every year (WHO, 2019). There is strong evidence that HAP leads to several major health hazards such as acute respiratory tract infections among children under 5 years, chronic lung diseases, lung cancer, cataract and cardiovascular diseases that increase the risk of cardiac events and strokes (Bruce et al., 2015; GBD 2016 Risk Factors Collaborators, 2017; WHO, 2014).

Women and infants are particularly affected by HAP, and HAP is among the most important health risks for these groups in many poor countries (see e.g., Smith & Sagar, 2014). Besides this direct health impact, the collection and processing of wood fuel draws heavily on the time of (mainly) women and children.

Moreover, the use of woody biomass as cooking fuel is also a significant driver of forest clearance and degradation when wood extraction is faster than regeneration (Hosonuma et al., 2012). CO_2 emissions and impacts on the local environment are the consequences of such land-cover changes. The incomplete combustion process further contributes to climate change as it releases climate-forcing gases and particles such as methane and black carbon. The severity of these effects depends amongst others on the efficiency of the cooking appliance used, as will be further discussed in 4.1.1.

Universal access to affordable and clean residential energy hence offers great potential for human development, economic growth, environment protection and climate change mitigation. In this context, multiple initiatives by governments and the global development community have promoted the transition away from traditional biomass cookstoves to more efficient and cleaner alternatives. These efforts, which are further discussed in Chapter 5, have focused on three main approaches. First, introducing improved biomass cookstoves (IBCs), i.e., more efficient and cleaner biomass stoves.[32] Second, producing and distributing more processed fuels like pellets, briquettes, ethanol or biogas and stoves that can burn these fuels efficiently or use other energy sources (e.g., solar cookers). Third, providing better access to liquefied petroleum gas (LPG) or electricity. Not all these alternatives are equally effective in achieving the desired benefits for climate change mitigation and human health as compared to traditional fuel use.

Moreover, even though fully displacing traditional cooking systems seems conceptually simple, it has turned out to be very difficult. Consequently, the number of people using traditional biomass for cooking has hardly decreased despite some encouraging developments in recent years (IEA et al., 2018, 2019). Users of traditional bioenergy sometimes reject alternative stoves or use them in addition to traditional stoves. Such kind of 'stacking' of traditional and modern fuels and appliances is a very widespread phenomenon (Cheng & Urpelainen, 2014; Ruiz-Mercado & Masera, 2015) which makes efforts to shift users away from traditional biomass stoves more difficult.

It is thus of central interest for research and development practice to identify the technologies and strategies that are most promising to foster household transitions to clean cooking technologies at scale. The remainder of this chapter summarizes the current scientific knowledge on both, the effectiveness of alternative technologies to traditional cookstoves and key drivers and barriers for residential energy transitions, as outlined above.

4.1 Evidence on health and climate benefits of LPG and IBC interventions

Scientists have been examining the negative consequences of traditional biomass cooking as well as the effectiveness of different alternatives technologies to address these consequences for several decades. Their focus has shifted over the years, whereby more comprehensive and nuanced evidence became available after the turn of the century. This section reviews the findings on LPG and improved biomass cookstoves, which have been the two globally dominant options in government programs and development cooperation, even though further clean fuels and appliances, e.g., those powered by electricity or biogas, are becoming increasingly relevant. The review focuses on benefits for climate change mitigation and human health as compared to the combustion of solid fuels in traditional stoves (for reviews see Bruce, Aunan & Rehfuess, 2017; Pope et al., 2017; Quansah et al., 2017; Thomas et al., 2015).

4.1.1 **Climate impact**

The climate impact of using a fuel for cooking depends primarily on the emissions at the point of fuel or stove use (Cashman et al., 2016). For the overall climate footprint of a product, one must consider the total emissions of each fuel per unit of usable energy provided though, i.e.,

[32] Reiterating from the introduction, I follow common practice by using the term *improved cookstove* for any kind of biomass stove that burns fuel more efficiently than a baseline stove or removes smoke from the indoor living space through a chimney.

over the whole fuel cycle from fuel sourcing to end use. This subsection discusses both perspectives starting with fuel combustion.

The climate impact of solid fuel combustion for cooking depends on the net greenhouse gases (GHG) emitted, in particular CO_2, but also methane and other gases and particles affecting the climate (so-called short-lived climate pollutants, SLCP). The type of fuel used and the amount of fuel needed determines how much GHG and SLCP are emitted to produce one meal. The amount of fuel depends on the cookstove's efficiency that is in turn determined by its thermal efficiency (i.e., combustion performance multiplied by heat transfer efficiency) and the carbon content of the fuel.

Burning fossil fuels such as kerosene or gas for cooking emits CO_2 emissions, while using renewable fuels, including renewably harvested woody biomass, is essentially CO_2 neutral. In practice, however, woody biomass is not always re-grown (IEA, 2016a). Bailis et al. (2015) estimate that about 27 to 34 % of woodfuel harvested globally is unsustainable, with large geographic variations. In parts of West, Southern and East Africa as well as some Asian countries such as Pakistan, Nepal and Indonesia, the non-renewably harvested fraction exceeds 50 % (Bailis et al., 2015; Masera et al., 2015).

When biomass is fully combusted, only water vapour and CO_2 are released. However, traditional cooking methods such as a clay 'U' or three-stone-fires are highly inefficient in combusting fuel carbon and transferring heat, which leads to excess fuel use and the release of numerous products of incomplete combustion (Schauer et al., 2001). These include pollutants like carbon monoxide (CO, a local pollutant), methane or black carbon (particulate matter) amongst others. Some affect both climate and health and others, such as methane, only the climate (e.g., Bond et al., 2013; Chafe et al., 2014; Conibear et al., 2018). Simple solid fuel stoves thus contribute importantly to global warming even when the fuel is renewable (Masera et al., 2015; Smith et al., 2000).

It is worth noting that the climate effect of black carbon is still the subject of scientific debate. According to the latest studies, black carbon is assumed to have a moderate climate-warming effect, depending on where and when it is emitted (Aamaas et al., 2018). The climate impact has found to be strong in the Artic (Sand et al., 2013; Sand et al., 2016) and the Himalayas (Ma et al., 2019). Importantly, residential cooking and heating based on traditional biomass use is the largest contributor to black carbon emissions (Aamaas et al., 2018).

Unlike traditional clay stoves, LPG stoves are characterized by an efficient (45 to 60 %) combustion process, with sustained performance under various conditions in everyday use and over time (Bruce, Aunan & Rehfuess, 2017; Shen et al., 2018). Combusting LPG thus emits only negligible amounts of black carbon and other (short-lived) pollutants that contribute to global warming (Grieshop, Marshall & Kandlikar, 2011). IBCs mostly have a higher thermal efficiency than traditional stoves and hence often result in reduced fuel wood use, as shown in several evaluations of cookstove interventions (Agurto Adrianzén, 2013; Bensch & Peters, 2013, 2015; Garland et al., 2015).[33] Concerning LPG, Brooks et al. (2016) and Garland et al. (2015) show that households relying on solid biomass for cooking reduce their fuel wood consumption substantially and realize important timesavings when being provided an LPG stove.

The efficiency of average IBCs is still substantially lower than for technologies based on liquid or gaseous fuels (Muralidharan et al., 2015; O'Sullivan & Barnes, 2006: 47). Several fan-assisted advanced biomass cookstoves have reached efficiencies (30 to 55 %) that come close to those of LPG when tested in the laboratory (e.g., Jetter et al., 2012; Kshirsagar & Kalamkar, 2014). While these controlled tests are useful to further develop and compare technology, they often poorly predict the real-world performance of the stoves. In particular, when in everyday use in homes, IBCs have been found to reduce fuel use and pollutants clearly less effectively than under laboratory conditions due to different reasons such as fuel quality or inadequate maintenance (Berkely Air Monitoring Group, 2012; Ezzati & Baumgartner, 2017; Muralidharan et al., 2015; Wathore, Mortimer & Grieshop, 2017).

As a result, the total warming effect of different fuel and stove types varies widely. Grieshop, Marshall & Kandlikar (2011) compare the global warming commitment of different fuel/stove combinations by combining emissions from individual stoves from five studies. Calculations are made based on estimated annual fuel usage per stove and under the assumption that for biomass (wood and charcoal), half of the total CO_2 emitted stems from the combustion of renewably harvested biomass and thus these 50 % do not contribute to climate change. Based on these assumptions and over a 100-year horizon, the authors find that the global warming impact of LPG is similar or even lower than the impact of the most advanced biomass stoves operating in optimal conditions. Their findings suggest a lower warming impact of LPG than biomass if a larger fraction of non-renewable biomass is assumed and a higher impact than biomass if a higher percentage of renewability is reached. In the light of the estimates mentioned above (Bailis et al., 2015) 50 % can be seen as conservative assessment for many countries, meaning that in these regions, LPG stoves would typically perform better than most biomass stoves.

While these calculations are based on hypothetical stove-switching, Singh, Pachauri & Zerriffi (2017) aimed to account for fuel-stacking and actual conditions. They estimate the net emission impact of the observed transition from biomass cooking to LPG in India between 2001 and 2011. They find that due to substantially higher efficiency of LPG, the switch to LPG causes essentially no net emissions. This would be true even if biomass was fully sustainably harvested and only Kyoto gases[34] were considered. When accounting for further climate-active emissions (that are not included in the Kyoto protocol), a switch to LPG results in a net reduction in emissions at the national level. The net reduction becomes even larger when assuming a more realistic share of 30 % for non-renewably harvested biomass.

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[33] Others found no effect of improved biomass stoves on biomass consumption, e.g., Hanna, Duflo & Greenstone (2016) or Nepal, Nepal & Grimsrud (2011).

[34] The Kyoto Protocol refers to the following six greenhouse gases, which are listed in Annex A: Carbon dioxide (CO2), Methane (CH4), Nitrous oxide (N2O), Hydrofluorocarbons (HFCs), Perfluorocarbons (PFCs), and Sulphur hexafluoride (SF6). More information can be found here: https://unfccc.int/resource/docs/cop3/07a01.pdf#page=28

So-called Life Cycle Assessments (LCA) of products allow to compare the environmental footprint of fuels over the full process, including the extraction from raw materials, the processing, distribution and the fuel use in the household and disposal. LCA for China and India by the United States Environmental Protection Agency (USEPA) show that the most important contributors to the total climate impact are a stoves' efficiency and the emissions resulting from their use. For LPG for instance, the emissions resulting from its production and transport account for less than 10 % of total emissions (Cashman et al., 2016). Regarding CO_2 equivalent emissions, the study estimates that the effect of LPG lies between fully and partially renewable biomass (in traditional stoves) in both China and India. For black carbon equivalent emissions, the effect of LPG (and of other clean fuels such as natural gas, biogas and ethanol) lies far below the one of biomass. Regarding improved stoves, USEPA finds comparably low climate effects for both CO_2 and black carbon. However, since these estimates are based on laboratory testing only, they should be treated with caution.

4.1.2 **Health impact**

Reiterating from the introduction to this chapter, there is strong evidence that HAP from solid biomass use leads to a number of major health hazards including respiratory diseases among children and adults, lung cancer, and cardiovascular diseases. The most significant adverse health effects of HAP exposure result from the emission of average fine particulate matter smaller than 2.5 µm ($PM_{2,5}$), while CO and other pollutants are also health-damaging (Bruce et al., 2015). The toxic smoke is often emitted directly into the indoor environment, resulting in emission levels of fine particulate matter that are estimated to be at least 10 to 50 times above the threshold for safe levels provided by the WHO (Puzzolo et al., 2016: 218). Emissions from solid fuel use also contribute to ambient air pollution (Chafe et al., 2014) and the health impacts associated with it.

Epidemiological research on HAP on the one hand aims to characterize appropriately how exposure to pollutants relates to specific health hazards (exposure-response relationship). To that aim, observational research measures personal exposure and uses it to determine the necessary pollution reductions to achieve health benefits (Ezzati & Kammen, 2001, 2002). Recent studies have found that the relationship between particulate exposure and health risks for most health outcomes associated with HAP exposure is non-linear. That is, exposure levels must be decreased to values close to the actual WHO guidelines for indoor air quality (10 µg/m^3) in order to prevent most of the adverse health effects (Burnett et al. 2014; WHO 2014).

Another avenue of research uses randomized control trials (RCTs) to measure the effects of interventions that aim to reduce HAP (i.e., the provision of cleaner cooking technologies/fuels) in real-world settings (e.g., Smith et al., 2011). As with greenhouse gas emissions, *laboratory tests* of improved cooking stoves suggest that their use reduces HAP and hence can improve health to some degree (e.g., Jetter et al., 2012). For LPG, Shen et al. (2018) ran 89 laboratory tests to measure efficiencies and pollutant emissions from different LPG stoves and burning conditions. The tested stoves meet guidelines for the highest performance levels according to international standards (see 6.2) in terms of thermal efficiency, CO and $PM_{2.5}$ emissions. Moreover, they mostly meet the WHO Emission Rate Targets for human health protection. In order to reduce indoor air pollution to a safe level for human health, households would have to use LPG or other clean fuels almost exclusively. However, especially in rural contexts, many households using LPG engage in stove-stacking to manage their cooking needs (see e.g., Brooks et al., 2016 for India). Similarly, many studies on improved biomass stove interventions face substantial problems due to low adoption and usage rates (Bensch, Grimm & Peters, 2015; Hanna, Duflo & Greenstone, 2016; Mortimer et al., 2017). Researchers thus emphasize that technologies must be tested in real-world settings, since user behaviour and fuel quality may undermine potential impacts (Hanna, Duflo & Greenstone, 2016: 85).

Concerning the *everyday in-home performance* of different solid and clean fuel interventions, the existing evidence is mostly based on observational designs. However, neither these exposure-response studies nor RCTs have so far provided as conclusive information as hoped for (see also Bruce et al., 2015 for an overview). Difficulties in measuring personal exposure to pollutants have limited exposure-response studies. In experiments, no interventions have been implemented that significantly reduce exposure while functionally replacing traditional biomass and coal stoves and being scalable in a community context (Ezzati & Baumgartner, 2017).

Regarding IBCs, several observational studies examined the health outcomes of the Chinese large-scale cookstove programme over a long period using data from a Chinese retrospective cohort study. They found that subjects with long-term use of improved chimney stoves showed substantial reductions in chronic obstructive pulmonary disease (Chapman et al., 2005), lung cancer (Lan et al., 2002) and reduced risk of mortality from acute lower respiratory infections (Shen et al., 2009). Regarding RCTs, Smith et al. (2011) tested the effect of stationary improved cookstoves with chimneys in a controlled setting in Guatemala and found no significant reduction in physician-diagnosed pneumonia for children younger than 18 months but a significant decrease in severe pneumonia and a reduced risk of low-birthweight. Based on the same RCT, Smith-Sivertsen et al. (2004) found no impact on women's lung function up to 18 months. In the Indian RCT on improved cookstoves by Hanna, Duflo & Greenstone (2016), while smoke inhalation was slightly reduced in the first year, this effect disappeared from the second year on. An experiment by Bensch & Peters (2015) suggests a decrease in self-reported smoke exposure and smoke-related disease symptoms after one year. The reduced smoke exposure mainly resulted from increased outside cooking and a decrease in cooking time. In a community-level, open cluster RCT in Malawi, Mortimer et al. (2017) found no evidence that providing cleaner burning biomass cookstoves reduced the risk of pneumonia in young children.[35]

Regarding LPG, the evidence from randomized trials is extremely limited so far. The first one to test the effectiveness of LPG to my knowledge is the Ghana Randomized Air Pollution

[35] Mortimer and colleagues assume that low usage-rates were partly responsible for these results. In the study, stoves were replaced and repaired where needed, in most cases several times per household. In the follow-up 2 years after stove introduction, those stoves objectively monitored were only used for 0.34 cooking events every day.

and Health Study, described by Jack et al. (2015). This cluster-randomized trial was launched in 2015 and provided LPG and efficient biomass cookstoves to pregnant women in intervention clusters to evaluate the efficacy of both technologies to improve health outcomes. First results after few years suggest that LPG use significantly decreases the risk for bacterial pneumonia (Lee et al., 2017). At the same time, Wylie (2017) found no evidence that providing LPG to pregnant women prior to 28 weeks improves birth weight. They concluded that in order to improve pregnancy health, whole clusters or communities should use clean energy. The Household Air Pollution Intervention Network trial, running 2018-2021 is doing exactly this in a multi-country RCT of an LPG stove and fuel intervention in Rwanda, Guatemala, India, and Peru (U.S. National Library of Medicine, 2016). There are no results available yet.

Findings from reviews can complement the evidence summarized so far. Quansah et al. (2017) provide a systematic review and meta-analysis on the effectiveness of any type of household intervention which was explicitly attempted to improve indoor air quality and/or health (RCTs and non-randomized control trials were included). Their results suggest that most HAP interventions achieved a decrease in $PM_{2.5}$ and CO concentrations at the personal and micro-environmental level. However, post-intervention measures were commonly still far above WHO guidelines for $PM_{2.5}$ and CO and there is hardly any evidence of improved health outcomes. Again, one of the reasons for this finding is that the relationship between particulate exposure and response has been found to be non-linear in medical research, which implies that smoke exposure needs to be reduced massively to ensure positive health effects (Burnett et al., 2014; WHO, 2014).

To conclude this part, the evidence reviewed above implies that the emissions from currently available biomass-burning stoves are more detrimental for health than from stoves fueled with LPG, electricity, ethanol or biogas. Moreover, field-based measurements of real-world usage show higher rates of $PM_{2.5}$ and other emissions than in laboratory tests. At the same time, the contribution of improved cookstoves to climate change mitigation and other SDGs (like reducing poverty or achieving gender equality) may be limited and in settings with high fractions of non-renewably harvested firewood, LPG is likely to outperform IBCs in terms of climate change mitigation. A modelling analysis by Rosenthal et al. (2018) for 40 low- and middle income countries using an integrated approach that considers both, health- and climate impacts to compare the benefits from cleaner fuels and improved cookstoves supports these conclusions. There are also difficulties to achieve the necessary health benefits with LPG that are mainly due to non-regular use. Yet, in this case, the intended health benefits can be achieved if LPG is used for cooking exclusively.

Long-term health studies remain limited and further research is needed on both LPG and biomass stoves. Yet these results have sparked an international debate on where donors should direct their resources in the sector that is at the center of the research work presented in Chapter 6.

In any event, materializing the benefits of cleaner and more efficient cooking appliances and fuels requires that households actually use these products frequently. A growing number of studies examines energy transition processes in the residential sector and aims to identify the factors that favor or impede the widespread adoption and use of cleaner and more efficient stoves and fuels. The following section presents some key insights from theses literatures with a focus on low-income and emerging countries, primarily drawing from studies in the field of economics.

4.2 Household fuel choices and barriers to clean cooking transitions

Early studies on domestic energy use commonly referred to the *energy-ladder* model, describing the transition from inefficient and polluting fuels like firewood or coal to the use of electricity and cleaner or 'modern' fuels such as LPG as linear movement, strongly driven by the household's economic status, namely income (Leach, 1992). Many empirical studies confirm that income is an important driver for the uptake and use of modern fuels (Farsi, Filippini & Pachauri, 2007; Gupta & Köhlin, 2006; Hosier & Dowd, 1987). However, the evidence indicates that the linkages between income and fuel choice are mostly weaker than suggested by the energy ladder and hence, fuel transition cannot be understood as a simple series of discrete steps (Hanna & Oliva, 2015; Heltberg, 2004; Masera, Saatkamp & Kammen, 2000). Instead, fuel wood can remain an important source of energy at all levels of income in developing countries. Just like in all countries, people prefer to combine different appliances and techniques when preparing meals, depending on the task. Furthermore, even if a household's average earnings are sufficient to buy modern fuels, the household may not be able to use these fuels exclusively if incomes are irregular or if the fuel supply is insufficient (Farsi, Filippini & Pachauri, 2007; Heltberg, 2004).

More recent studies place greater emphasis on such complexities and therefore use broader conceptual frameworks for analysis which account for the countries' external environments, the institutional setting, the market situation of a specific location, and the household opportunity set (e.g., Manning & Taylor, 2014. See Muller & Yan, 2018 for an overview on theoretical frameworks and empirical evidence).

Apart from the household's wealth, the empirical literature identified several other determinants of household fuel choices. They include further socio-demographic characteristics like the age of the household head, the household size and composition (share of women, gender of household head) with mixed findings concerning the effects on fuel use (van der Kroon, Brouwer & van Beukering, 2013). Higher educational attainment is generally associated with a higher probability to use modern cooking energy, since education increases both income and the opportunity costs of fuel collection time and enables better knowledge about the benefits of cleaner cooking fuels (Farsi et al., 2007; Gupta and Köhlin, 2006).

Recently, scholars have increasingly integrated the social and cultural environment of the household into their analysis. Akpalu, Dasmani & Aglobitse (2011), for instance, find evidence that traditions, taste preferences and cultural beliefs play a significant role for household cooking fuel decisions. Regarding the market environment, many studies confirm the expected negative own-price effects on both the probability to use a fuel and the quantity demanded (e.g., Cheng & Urpelainen, 2014; Farsi, Filippini & Pachauri, 2007). Farsi, Filippini & Pachauri

(2007) estimated for instance that, among urban Indian households, decreasing LPG prices by 10 % would increase the average proportion of LPG consumers by approximately 7 % and decrease the share of kerosene and wood users respectively. Cross-price elasticity is discussed more controversially, with some scholars identifying fuel substitutions driven by cross-price effects, while others do not find significant substitution effects (see review by Muller & Yan, 2018: 433).

While the above studies discuss household fuel choices in general, there is a further, closely related strand of literature that directly addresses intervention programs for clean energy transitions and that examines drivers and barriers to the wider use of cleaner cooking technologies. Much of this research refers to the adoption of improved biomass cookstoves, which, despite decades of efforts (see Chapter 5), are still far from widespread.

In the first decades of cookstove programs, there were relatively few analyses that evaluated these interventions and examined what made them succeed or fail (for an early review see Barnes et al., 1994). Lewis & Pattanayak (2012) note that when initial attempts to impose untested technologies on hesitant households and consumers failed, research in the area focused primarily on demand-side factors. According to the authors, the focus on demand was underpinned by a growing body of literature which suggested that consumers often did not know or appreciate the benefits of health technologies such as water filters, improved stoves or insecticide-treated bed nets and hence do not invest in or use them (e.g., Rhee et al., 2005).

Stove designs that did not meet user needs (Kishore & Ramana, 2002; Mobarak et al., 2012; Rosenbaum, Derby & Dutta, 2015) and ineffective financing and distribution models were further barriers that have been discussed since very early on in the context of stove interventions, together with factors that had already been identified in the more general literature, such as consumers being unable or unwilling to pay for costly new stoves and fuels (Masera, Díaz & Berrueta, 2005) or limited educational attainment (El Tayeb & Mukthar, 2003). Low adoption rates have also been attributed to the division of tasks and decision-making processes within households (Troncoso et al., 2007).

In the past decade, the body of evidence on the determinants of the adoption and use of improved biomass stoves (and sometimes clean fuels) has grown fast. Hereby, qualitative and observational research has been complemented by a growing number of experimental studies, examining, amongst other things, the effects of different pricing and dissemination models (Beltramo et al., 2015; Bensch & Peters, 2019; Levine et al., 2018; Rosenbaum, Derby & Dutta, 2015). Most recently, researchers have assessed household preferences when offered a range of different cleaner cooking options. In this context, Menghwani et al. (2019) found that most participants chose the cleanest alternatives, i.e., LPG and induction stoves, regardless of price. Users' knowledge and perception of the technologies' benefits such as smoke reduction, fast cooking (in the case of LPG), safety or cleanliness positively influence the uptake of improved stoves or clean fuels (see Rehfuess et al., 2014 and Puzzolo et al., 2016 respectively for overviews).

The above discussion highlighted a number of key factors associated with households' transition to more efficient and clean energy for cooking. More comprehensive reviews of barriers and enablers to the adoption and use of cleaner cooking technologies are provided by Lewis & Pattanayak (2012), Rehfuess et al. (2014), Puzzolo et al. (2016), and, for IBCs in India, by Khandelwal et al. (2017).

One of the key findings from the literature discussed here is that the adoption of cleaner fuels or cookstoves commonly results in the combined use or stacking of modern and traditional fuels and stoves, while full replacements are very rare (Cheng & Urpelainen, 2014; Masera, Saatkamp & Kammen, 2000; Ruiz-Mercado et al., 2011). Therefore, clean cooking interventions that enable the adoption of a cleaner cooking technology, e.g., by covering initial investment costs, often do not result in the sustained use of the technology, as has been shown for improved cookstoves (Hanna, Duflo & Greenstone, 2016) and for LPG (Kar et al., 2019). This issue is still insufficiently considered in research and practice.

Given that a substantial reduction in toxic air pollution essentially requires a complete switch to clean cooking fuels and stoves, it is therefore essential to go beyond mere technology adoption in order to explore how long-term acceptance and almost exclusive use as a next stage can be achieved. Yet, existing research primarily examines the adoption of clean cooking fuels (Puzzolo et al., 2016), while only very few studies (e.g., Gould & Urpelainen, 2018) offer more comprehensive insights by also looking at drivers and barriers to the frequent use of clean technologies.

In the case of LPG, which takes on a central role in this dissertation, it is known that the initial investment cost (for the stove, cylinder, regulator, pipe) is a crucial obstacle to widespread adoption, especially for poorer households and those who gather firewood free-of-charge (Edwards & Langpap, 2005; Gould & Urpelainen, 2018; Puzzolo et al., 2016).

Promoting a transition to almost exclusive use, however, requires a systemic perspective, since affordable and reliable fuel supply is key for consumers of fuels like LPG or ethanol. In this context, recent reviews and meta-analyses emphasize the role of government facilitation through, e.g., subsidies, regulation or market development and the need to take into account the multiple levels involved in clean cooking interventions, from the household up to the national level (e.g., Puzzolo et al., 2016; Quinn et al., 2018).

More specifically, alongside the previously discussed socio-economic and cultural characteristics of the household that hardly vary in the short term, the market situation (e.g., reliable supply) and specific policy measures must be examined. Measures aimed at making access affordable for poor, rural households and providing them with the necessary knowledge deserve special attention here.

Indeed, existing studies do indicate that poor, rural households are often unable to make the transition without additional financial support, particularly in the case of LPG (Gould & Urpelainen, 2018; Puzzolo et al., 2016), and they document successful examples of widespread LPG uptake through subsidies (Andadari, Mulder & Rietveld, 2014; Lucon, Coelho & Goldemberg, 2004; Troncoso & Soares da Silva, 2017). Apart from few case studies (Benka-Coker et al., 2018; Jain, Agrawal & Ganesan, 2018), there is, however, a lack of systematic research on how LPG subsidies could be designed to provide effective access to vulnerable groups, on the feasibility of targeted subsidies for selected groups, and on the sustainability of such subsidies for the countries concerned (Puzzolo et al., 2016).

More generally, most academic and grey literature on fossil fuel subsidies examines them from the perspective of subsidy reform (see 2.2). In terms of energy access aspects, the focus lies on the overall unequal benefits of universal subsidy schemes (Arze del Granado, Coady & Gillingham, 2012) and their failure to provide energy access to the poor. While eliminating and reforming fossil fuel subsidies is highly justifiable on many grounds, differences between fuels and purposes and the specific role of fuel subsidies for clean cooking as outlined above are not sufficiently considered.

Alongside the challenging aspect of subsidies, awareness campaigns are another key policy instrument that has been insufficiently analyzed so far. Only a few studies examine the effect of information on the health benefits of cleaner technologies on their uptake and use (Beltramo et al., 2015; Mobarak et al., 2012). These studies, which find no consistent evidence for the effectiveness of health messaging, are primarily related to the introduction of improved biomass cookstoves. The effect in the context of transition to LPG has hardly been examined yet (a notable exception is Krishnapriya, 2017).

This thesis will address some of the above-mentioned research gaps in a study on transitions from solid biomass to LPG use presented in Chapter 7. We focus on households in rural India that adopted LPG, but do not use it frequently, and evaluate whether simple health messaging can increase households' willingness to pay for LPG and their propensity to use it regularly.

In the following Chapter 5, the thesis proceeds with an overview of energy transitions in the household sector, turning now to the actors who have been trying for decades to accelerate this process. As the historical outline on clean cooking interventions will show, donors set very different priorities in the context of these interventions, with potentially significant developmental consequences. Chapter 6 will therefore assess the political-economic and ideological rationale behind this divergence of strategies.

5 A BRIEF HISTORY OF CLEAN COOKING INTERVENTIONS

For over forty years now, international organisations, national governments and other actors have sought to address the multiple problems surrounding solid biomass use for cooking. This chapter traces key developments in clean cooking efforts and shows how the focus and the approaches of these interventions have evolved in response to the changing understanding of the problem over time. It hereby concentrates again on improved biomass cookstoves and LPG, i.e., the two major alternatives to traditional cooking practices.

5.1 Early interventions for forest conservation

Earliest efforts to promote improved cookstoves in developing countries date back to the late 1940s, but with only few stoves actually built for use (Krugmann, 1987). In the 1970s, rising concerns over the oil price hike and its negative impact on the poor combined with fears, that harvesting of fuelwood for cooking by a large and growing number of people would lead to mass deforestation (Eckholm, 1975). This led to a wave of cook stove projects, mainly funded by international agencies, in the mid and end 1970s (Krugmann, 1987).[36,37]

In 1983, already 100 cookstove programs were initiated according to the Food and Agriculture Organization of the UN, FAO (Joseph, 1983) with many governments and "virtually all international donor agencies […] involved in one or more of them [...]" (Krugmann, 1987: 3). In the context of the perceived fuelwood crisis, cookstove programs mainly aimed at increasing fuel efficiency, improving energy supplies for the concerned population and mitigating the pressure on forest biomass (Arnold et al., 2003; Urmee & Gyamfi, 2014). The conventional wisdom at that time was that existing traditional stoves have an extremely low energy efficiency such that simple design changes could lead to huge efficiency benefits (Barnes et al., 1994).

[36] The concerns over the 'fuelwood crisis' were later prominently exemplified in the Brundtland Commission report *Our Common Future* (Brundtland, 1987).

[37] As a consequence of the oil crisis, it became much more difficult to switch to modern fuels like LPG for cooking, so it was predicted that dependency on biomass would persist for longer than previously assumed, see Barnes et al. (1994).

While the programmes were projected to set up millions of stoves in the 1980s, disillusionment followed soon. According to Manibog (1984: 203), less than 100,000 stoves were distributed worldwide after years of effort and a considerable proportion of them were either not used or only used occasionally. Furthermore, the inability to demonstrate measurable firewood savings across many households raised serious doubts about further engagement in cookstove programmes (ibid.).

The failure to achieve large-scale diffusion and widespread use of improved cookstoves was addressed in a review by Barnes et al. (1994), which suggests that stoves at that time were based on questionable design principles with little influence of user input and that projects suffered from poor monitoring and evaluation. Not very surprisingly, households in the target population were often not very enthusiastic about adopting a stove. In addition, regarding potential fuelwood savings and the role of cookstoves for forest conservation, over time more nuanced analyses were conducted, which showed that other pressures like timber extraction and demand for cropland are usually the main drivers behind changes in forest cover (e.g., Leach & Mearns, 1988). Together, the challenges of dissemination and the uncertain link between residential wood fuel use and deforestation, lead to a decline in early donor interest in cook stoves (Bailis & Hyman, 2011).

Early efforts to promote alternatives to traditional cooking appliances also involved support for modern cooking fuels like LPG. LPG was notably promoted by national governments through large-scale programmes, e.g., in Brazil and Senegal from the 1970s onwards (Fall et al., 2008; Goldemberg et al., 2018; Lucon, Coelho & Goldemberg, 2004). Improving access to modern fuels as an alternative to IBC funding was also occasionally referred to by actors in the international development community, notably by the World Bank (Barnes et al., 1994). However, leading publications like the World Development Report concluded that modern fuels would remain unaffordable and unavailable for a large proportion of the population, making the transition to commercial fuels difficult and long (Barnes et al., 1994; World Bank, 1992). These reports also highlighted that making modern fuels accessible would require loans or subsidies for appliances and fuel, whereas particularly subsidies on fossil fuels create other problems like wasteful consumption (see Chapter 2).

5.2 Cookstoves to reduce indoor air pollution

In the end late 1980s and early 1990s, an increasing number of scientific publications emphasized that smoke from burning biomass in traditional cooking stoves led to high levels of HAP with health-threatening effects (Chen et al., 1990; Smith, 1987, 1993). Consequently, the concept of improving cookstoves with chimneys or other elements to reduce direct exposure to health-damaging pollutants became popular. Hence, while initial efforts to promote improved cookstoves were driven primarily by the aim to conserve forests, now the social and health benefits from reducing air pollution were at the core of most improved stoves programmes. The environmental motivation remained nevertheless important and was underpinned by publications in the mid-1990s which described HAP as critical environmental problem (due to the global warming potential of biomass combustion) and highlighted the relevance of energy efficient cookstoves in this context (Barnes et al., 1994; World Bank, 1992). In the late 1990s, donors began to prioritise public health, which opened up new financing channels for cookstove programmes (Bailis & Hyman, 2011).

Large government programs for improved biomass cookstoves were launched in China, India, Bangladesh, Sri Lanka, Nepal, and some African and Latin American countries (Urmee & Gyamfi, 2014). Some of them were successful. China, for instance, implemented largely successful programs since the 1980s, which provided the majority of households in rural areas with better biomass and coal stoves that were actually used (Sinton et al., 2004; Smith et al., 1993). Another government program which was relatively successful was the dissemination of about 1 million improved charcoal stoves, the so-called 'Jiko'-stoves in the 1980s and 1990s in Kenya (Daniel M. Kammen, 1995; Hyman, 1987).

Dozens of development organizations have developed IBC projects, too, since the mid-1990s. However, most of them could not be scaled up to more than a few thousand stoves (Bailis et al., 2009). In this context, researchers like Robert Bailis and Omar Masera argued that a main challenge for improved stoves was that donors – in line with the general shift towards more neoliberal approaches to development – increasingly emphasized market-based approaches to stove dissemination and disfavored (partially) subsidized models (Bailis et al., 2009; Bailis & Hyman, 2011). So, even though cookstoves were praised as instruments to provide public goods such as public health and environmental conservation – and such goods typically require financial assistance – "[…] in the case of stoves, by the 1990s such assistance lost popularity" (Bailis & Hyman, 2011: 60).

With regards to core World Bank departments concerned with household energy, a staff report describes declining attention and resource allocation: "The focus on household energy access remained strong between 1988 and 1994", "[…] a shift came in the mid-1990s, when household energy access activities declined during the 1996–97 period as growing attention focused on rural electricity access" (Ekouevi & Tuntivate, 2012: 14). The lower policy attention for biomass energy and cooking fuels cooking energy at the turn of the century and beyond has been related to an ongoing uncertainty in the development community about the potential for further stove-promoting interventions (Arnold, Köhlin & Persson, 2006; Ekouevi & Tuntivate, 2012). Factors underpinning this pessimism were the recognition that the 'fuelwood crisis' had been exaggerated and a lack of consistent evidence that improved stoves did generate health-benefits and were relevant to the concerned communities (DFID, 2002); Arnold et al. 2006). At the same time, a common normative framework on the international level for this crosscutting issue was missing for a long time, as described in the following section.

5.3 Sluggish international coordination

Due to the historically close links between energy, economic development and national security, governments have always been reluctant to address energy issues in a multilateral context. Therefore, there was essentially no institutionalized cooperation and norm development on energy in the UN System and beyond during roughly five decades after it was founded (Karlsson-Vinkhuyzen, 2010).[38] This normative vacuum also concerned energy issues in developing countries: while there were diverse activities by bi- and multilateral development agencies, the Bretton Wood institutions and national governments, these activities were greatly fragmented and the choice over which energy sources and services being supported was guided by the individual priorities of the initiating institutions (Karlsson-Vinkhuyzen, 2010).

Only when environmental concerns gained prominence on the international stage, energy became increasingly discussed from a different perspective and a series of events marked the emergence of global agendas and institutions on sustainable development. The first UN Conference on Environment and Development in Rio de Janeiro 1992 strengthened the link between energy, development and the environment, especially in the context of climate change. The 'Agenda 21' – a non-binding action plan adopted in Rio – suggested that governments increase efforts to improve efficiency, reduce demand, promote renewable energy and cleaner technologies (UN, 1992). Regarding household energy access, governments should support the use of alternative sources of energy and improved stoves in order to reduce pressure on wood resources (UN, 1992: par. 12.18).

In the 2000s, general energy issues finally gained a more prominent role on the UN agenda in normative as well as institutional terms (Karlsson-Vinkhuyzen, 2010). Policy attention on the problems caused by domestic biomass use first remained low though, as exemplified by the adoption of the *Millennium Development Goals (MDGs)*: These eight global development targets for 2015 that were established following the UN Millennium Declaration in 2000 included a specific goal (MDG 7) to ensure environmental sustainability (UN, 2000, 2001). It was mainly concerned with greenhouse gas emissions and deforestation, encouraging governments to integrate principles of environmental sustainability into country policies and (development) programmes. Reducing HAP is also contributing to the achievement of other MDGs, such as gender equality (MDG 3), reducing child mortality (MDG 4) and improving maternal health care (MDG 5). However, none of the MDGs explicitly referred to domestic energy use or air pollution. Hence, like in the action plan adopted in Rio 1992, access to modern energy as a basic need to reduce poverty and improve health remained neglected.

Energy as a crosscutting issue of economic, social and environmental development was for the first time discussed as separate agenda item on the international level in the 9th meeting of the UN's Commission on Sustainable Development (CSD) in 2001.[39] While the meeting was characterized by difficult negotiations, the adopted decision emphasized that energy services are crucial to eradicate poverty (UN Commission on Sustainable Development, 2001). The Johannesburg World Summit on Sustainable Development (WSSD) in 2002 prominently

[38] The only major international organisation at the time was the IEA. It was founded in 1974, essentially to support states in the coordination of efforts to deal with major disruptions in the oil supply. Today it sees itself as a key part of the global dialogue on energy by providing analysis and policy recommendations in a wide range of areas. Only OECD countries can become member of the IEA. For further information, see https://www.iea.org/.

[39] The CSD was founded in 1993.

repeated this new recognition of energy access as a precondition for development and poverty reduction. Hence, in the global energy discourse, while energy had been linked to sustainable development only in terms of being a source of environmental stress and as major driver of economic growth, now it was also seen as pre-condition to fulfill basic human needs (McDade, 2004; Najam & Cleveland, 2003).

The WSSD summit marked the launch of the Shell Foundation and the Partnership for Clean Indoor Air (PCIA). 590 partners, including governments, industry and NGOs, joined the PCIA over the years.[40] Briefly after the WSSD the United Nations Development Programme (UNDP) launched a partnership with the World LPG Association (WLPGA) to promote affordable and accessible LPG for people in developing countries. In a project called *Rural Energy Challenge*, the WLPGA examined rural LPG use in seven countries.[41] All of these initiatives had the character of loose networks whose activities were limited to capacity building and technology transfer. Hence, energy and energy access remained issues without 'institutional home' in the UN system (Spalding-Fecher, Winkler & Mwakasonda, 2005). In addition, the world leaders at WSSD did not agree on targets for improved energy access (nor for renewable energy), nor did they commit to significant resources to increase access to energy services.

Thus, while energy was widely recognised as an essential means to achieve many development objectives in all sectors, specific energy measures, in particular those related to the role of heat and fuels, were still underestimated (McDade, 2004). The neglect of the issue in global development cooperation frustrated some. Drawing from the ongoing discussion about the historical responsibility of industrialized countries for greenhouse gas (GHG) emissions, a senior UNDP manager of the sustainable energy program and environmental health scientist K. Smith criticized the neglect of fuels in development assistance efforts. They argued that it was partly because environmental protection arguments would direct development assistance funding for energy and that it raises equity concerns (McDade, 2004; Smith, 2002).[42]

In 2005, an advisory body commissioned by the UN Secretary General to propose the best strategies for meeting the MDGs, identified access to basic energy services as an area not included in the formal Goals framework, but of vital importance for the achievement of the goals. The commission suggested that in order to help achievement of the goals by 2015, countries should aim to reduce the number of persons without access to modern cooking fuels by half and make improved cookstoves widely available (UN Millennium Project, 2005: 30).

[40] The partnership existed 2002-2012 and was then integrated with the Global Alliance for Clean Cookstoves. It had four priority areas: addressing social/cultural barriers to adopting improved technology; supporting the development of local business models and markets for improved cooking and heating techniques; improving the design and performance of improved fuels and technology; and demonstrating reduced exposure to indoor air contaminants.

[41] They held multi-stakeholder workshops in seven countries between 2003 and 2007: Ghana, Honduras, South Africa, Morocco, Vietnam, China and Turkey.

[42] While climate justice is an important argument to be considered in the debate that is subject of this work, the normative perspective is beyond the scope of this chapter and will hence not be further discussed.

Yet, national energy strategies, plans for poverty reduction and achieving the MDGs and for implementing multilateral environmental agreements (e.g., on climate change)—formulated with support of bi- or multilateral development agencies—often neglected energy challenges and remained unconnected. Moreover, there was still a lack of any large-scale financing for biomass energy and cooking fuels throughout the first decade of the new millennium (Sagar, 2005).

5.4 Regaining traction for climate change mitigation and health potential

The Kyoto Protocol, adopted 1997 to implement the United Nations Framework Convention on Climate Change (UNFCCC), entered into force in 2005, with the first commitment period starting 2008. In the context of the ratification, improved biomass stoves regained attention due to their climate mitigation potential. Recent issues in the climate change discussion added further interest: the role of fuelwood dependence in deforestation was again discussed in the context of REDD (reduction of emissions from deforestation and degradation) and traditional stoves have been identified as an important source of black carbon aerosols, which are powerful climate warmers (Bailis & Hyman, 2011; Hansen & Nazarenko, 2004).

Similarly, further evidence on the health risks related to traditional woodfuel cooking practices was published (e.g., Díaz et al., 2007; Smith-Sivertsen et al., 2004). In a landmark publication, the WHO (2006a) emphasized that these serious public health risks had so far been neglected and that since 1990 there was hardly any progress to improve access to modern cooking. The report also highlighted that—where this is possible—switching to modern fuels like LPG or biogas was the most effective way to reduce indoor smoke.

This greater evidence on and revived interests in the manifold aspects of household cooking energy was reflected in a rising number of reports within multilateral organizations[43]. Hence the issue of cooking energy started to (re)gain momentum on the agenda of international development cooperation towards the end of the 2000s (Kees & Feldmann, 2011), this time with was a strong push from health and climate concerns.

Against this background, improved cookstoves were not only designed to save fuelwood anymore, but were supposed to address a whole range of issues such as local health and environmental implications, as well as the global impacts associated with GHG (Masera, Díaz & Berrueta, 2005). The new generation of improved biomass cookstoves becoming available commercially had an advanced design and were more effective than before (e.g., MacCarty, Still & Ogle, 2010).

The renewed interest has also been associated with the availability of (new) funding opportunities, particularly those related to international climate finance or carbon markets (Bailis et al., 2017; Kees & Feldmann, 2011; World Bank, 2011).[44] While for a long time, clean cooking (specifically cookstoves) had been promoted predominantly through small, donor-funded

[43] Key multinational organizations publishing on the topic included the World Bank, the World Health Organization, the UNDP and the IEA.

[44] Financing of clean cooking projects through carbon markets and public climate finance will be discussed in detail in Chapter 6.

give-away programs, the renewed interest triggered several large initiatives, which promised a major boost for clean cooking efforts (see 5.5). There were also renewed efforts by national governments. The government of India for example re-launched a large-scale IBC program in 2009 (GOI, 2013).[45]

On the multilateral level, Energising Development (EnDev), an initiative launched by Germany and the Netherlands in the aftermath of the Johannesburg Summit, became a partnership of bilateral donors from Northern and Central Europe in 2009.[46] EnDev aims to provide poor households with modern energy services by supporting access technologies based on renewable energies such as photovoltaic systems or improved biomass cookstoves or biogas.

5.5 High level platform initiatives and slow progress

In 2010, the Global Alliance for Clean Cookstoves (henceforth 'the Alliance') promised a concerted and rigorous push to improve climate and health outcomes by making clean cookstoves and fuels available to 100 million households until 2020. Hosted by the UN Foundation, it brought together a large network of partners ranging from multilateral organizations to academic institutions in order to create a global industry for clean cooking solutions.

The need to act on energy poverty in a coordinated manner was now also recognized within the UN system. Based on recommendation by the Advisory Group on Energy and Climate Change (AGECC), Ban Ki-moon launched the Sustainable Energy for All (SEforALL) initiative in 2011, a global platform supposed to catalyze action on the issue. SEforALLs goals are to achieve universal access to modern energy services (including electricity and clean cooking equipment), to double the global rate of improvement in energy efficiency, and to double the share of renewable energy in the global energy mix. The UN General Assembly further declared 2012 as the International Year of Sustainable Energy for All (AGECC, 2010; UN, 2011). Under the SEforALL Initiative, multilateral development banks, bilateral donors and the private sector made financial commitments to improve modern access to energy. These pledges corresponded, however, to only a mere fraction of the investment needed to achieve universal access to modern energy (Birol, 2014).

In 2012, SEforALLs chief executive Kandeh Yumkella encouraged Kimball Chen, then the president of the WLPGA, to establish an organisation with non-profit status, but as a public-private partnership, to help scale up LPG adoption for clean cooking in low- and middle- income countries. Chen put together a group of experts to establish Global LPG Partnership (GLPGP). Global LPG Partnership partners with host country governments upon their invitation – namely eight African countries – and other actors to establish national plans to scale-up LPG infrastructure, distribution and demand and provides assistance for the financing and

[45] Despite massive promotion over many decades through this and earlier programs, the adoption of IBCs in India has remained very limited though, see Khandelwal et al. (2017).

[46] EnDev is financed and led by the governments of the Netherlands, Germany, Norway, the United Kingdom, Switzerland, and Sweden. Further financial supports (for bilateral individual country projects) have come from Irish Aid, the EU, USAID, and the Australian Government Department of Foreign Affairs and Trade (DFAT).

implementation of key plan elements, e.g., with microfinance programs (GLPGP, 2018). The fact that Chen as well as a part of GLPGP staff previously worked in the oil- and gas industry led to confusion in the sense that many actors in the sector thought of GLPGP as a private sector oriented organization (personal communication).[47]

The SEforALL goals link closely to the SDGs and the Paris Climate Agreement, both adopted 2015 (see also 6.3.1). In the context of the Paris Agreement, clean cooking was widely discussed as important component of mitigation efforts that also address the needs of the poor. Energy is also at the core of the UN's Sustainable Development Goals, which, unlike the MDGs discussed above, explicitely refer to energy with SDG 7 calling for universal access to affordable, reliable, sustainable and modern energy for all. Furthermore, implementing clean cooking technologies in low-income households will drive progress towards several of the other SDGs such as health and wellbeing (SDG 3), empowering women and girls (SDG 5), sustainably managing forests and halting land degradation (SDG 15) or combatting climate change (SDG 13) (Rosenthal et al. 2018).

The appeal of cookstove interventions had also been (re-)discovered within the World Bank. A 2011 publication in support of the Bank's re-engagement in the issue emphasized that "[t]he value chain around cookstoves—perhaps the simplest and oldest household technology—presents an opportunity to put the integrative idea of sustainable development into practice" (World Bank 2011, v). At the same time, the World Bank, together with political decision makers and academics, also increasingly recognized that gas for cooking is an important part of the efforts to reach widespread access to clean energy. A comprehensive staff report assessed LPG markets and its use in various low-income countries and provided suggestions for governments and industry on how to promote LPG such as modernizing regulatory frameworks or improving the supply and transport infrastructure, while recognizing the limitations of price subsidies (Kojima, 2011).

After a period of low attention in the end 90s, the World Bank started providing assistance related to cooking and heating energy through its Energy Sector Management Assistance Program (ESMAP), the Regional Program for the Traditional Energy Sector and the Biomass Energy Initiative for Africa. Apart from comprehensive analytical work and policy support, lending operations with household energy components were initiated after 2002 (Ekouevi & Tuntivate, 2012). World Bank financed projects that were launched before 2011 and had a component on access to fuelwood or stoves, focused mainly on Sub-Saharan African countries and primarily involved the distribution of large numbers of improved biomass cookstoves. However, in Mali, Niger and Senegal, where the governments were already running own interfuel substitution programs, the World Bank projects promoted the commercialization of both kerosene and LPG stoves by private entrepreneurs with a focus on subsidies supporting small-size LPG cylinders (see Ekouevi, 2013 for an overview on all projects).[48]

[47] This information is part of self-collected survey- and interview data from key representatives in the clean cooking sector which is used for the study presented in Chapter 6. All methodological details are provided there.

[48] The Bank further funded four projects supporting biogas for cooking and lighting in China and Nepal and eight on natural gas for cooking and heating, mostly in Europe and Central Asian countries, see Ekouevi (2013).

Since about 2012, the World Bank has significantly scaled up its support to clean cooking and by end 2017 managed a portfolio of $130 million in this sector (World Bank, 2017a). Collaborating with the Alliance, SEforALL and bilateral donors and through ESMAP, the Bank has launched several large regional initiatives. These initiatives include the Africa Clean Cooking Energy Solutions initiative (2012-2014), a technology and fuel-neutral platform for enterprise development in Sub-Saharan African countries, and the East Asia and Pacific Clean Stove Initiative, which is piloting and providing result-based financing for clean stoves since 2012 in China, Indonesia, Lao PDR and Mongolia (World Bank, 2012; Zhang & Adams, 2016). While these programmes mainly work through awareness raising, capacity building and the mobilization of private sectors actors and NGO's, the World Bank's South Asia Household Energy Initiative aims to disseminate directly 1 million improved cookstoves in Bangladesh (Jain & Sadeque, 2017). Since end 2014, the World Bank officially collaborates with the cookstove Alliance in the Efficient Clean Cooking and Heating Partnership to support in-country projects undertaken by both organizations.[49]

Not only international development programmes by the World Bank and other international institutions, but also a variety of NGO-, government-led or private-initiative cookstove programs had surfaced during these years and "[…] cookstove programs have become a global enterprise" (Urmee & Gyamfi, 2014: 630). The increased prominence of the issue was also reflected in ambitious targets for scaling up household energy interventions that have been set by a number of national governments, including China, India, Ghana, Bangladesh, Guatemala, Nigeria, and Kenya, often in partnership with international agencies (GACC 2016, Urmee and Gyamfi 2014). Ghana, for instance, aimed to transition 50 % of households to LPG as primary cooking fuel and provide access to improved biomass cookstoves by 2 million households. Kenya set its LPG penetration-target at 18 % in 2020 (35 % in 2030) and aimed to reach 5 million additional households with improved cookstoves.[50]

Thus, within just a few years, household energy for cooking and heating has become well established on the agenda of international organizations. The dominant context for debates about cooking interventions was now the health-climate nexus, given the Paris agreement, the SDGs, but also a number of publications that further emphasized the need for urgent action on the issue based on the massive global health burden from HAP (GBD 2016 Risk Factors Collaborators, 2017; WHO, 2014) and medical research emphasizing the need to decrease exposure levels to extremely low values in order to improve health outcomes (Burnett et al., 2014; WHO, 2014) (see 4.1.2).

Against this background and given that for a wide range of improved biomass cookstove technologies no significant health benefits could be achieved (see 4.1.2), standards for the performance of stove technologies and fuels that were being developed since 2005 became more

[49] In the initial stage, the partnership has been supporting activities in 12 countries where the World Bank Group and the Alliance are active in clean cooking programs, including the eight Alliance focus countries – Bangladesh, China, Ghana, Guatemala, Kenya, India, Nigeria, and Uganda. Projects include the dissemination of super clean gasifier cookstoves in LAO, the support of LPG in Kenya, a result-based financing pilot of clean cookstove in Indonesia and the continued support to a clean cookstove project in China.

[50] See the SEforALL country action agendas for Ghana and Kenya.

important (see 6.3.1). In this context it is worth noting that the World Bank has adopted a result-based financing approach where based on the clean cooking performance, financial incentives are provided for the private sector to deliver clean cooking services.

Yet, most of the stoves distributed by the Alliance and its partners did not meet the performance requirements for sufficient emission reductions of $PM_{2.5}$ and CO (Bruce et al., 2015; GACC, 2017; WHO, 2014). In addition, even if the promoted IBCs achieved the health benefits required, they were often not (regularly) used in households (see 4.2).[51] The fact that the Alliance has lagged far behind its objectives has also been the subject of prominent media reports (Morrison, 2018).

Hence, on the one hand, the Alliance and its partners managed to increase levels of attention and funding to the issue and the global cookstove market experienced a big shift over the years since its formation, with several for-profit manufacturers selling remarkable numbers of stoves, global standards and testing centers to compare stove qualities (GACC, 2017; Putti et al., 2015). On the other hand, despite all major, coordinated efforts described above, their success in providing access to clean stoves and fuels was very limited so far.

The observation that "progress on clean cooking remains painfully slow" [52] is documented well in the Energy Progress Report,[53] which tracks global progress towards access to clean cooking and other SDG 7 targets. While overall progress falls short on meeting all SDG 7 goals, usage of clean cooking fuels and technology is lagging furthest behind. Between 2010 and 2017 access to clean cooking solutions increased by only 0.5 pps per year. This would leave about one third of the global population with no access to clean cooking by 2030 if the growth rate seen 2010-2017 is assumed (IEA et al., 2019).

One of the major factors underpinning the unsatisfactory development in the sector is that despite the increased awareness, only few large-scale interventions have been triggered so far and profoundly needed, large-scale funding is still missing in the sector (IEA et al., 2019: 56; SEforALL & CPI, 2018), an issue further discussed in 6.3.2.

5.6 Increased emphasis on LPG

In the light of the increased emphasis on clean fuels and stoves to generate health benefits, interventions in the last few years suggest some increased efforts to promote LPG use. Countries in the Economic Community of West African States (ECOWAS) for instance, coordinated their LPG targets for clean cooking under the guidance of the ECOWAS Centre for Renewable Energy and Energy Efficiency, which funded the West African Clean Cooking Alliance in 2012 to support and coordinate national and international efforts on the issue in the region.[54] Some

[51] The stacking issue is also pertinent for LPG though.

[52] Message of Clean Cooking Alliance CEO Dymphna van der Lans, May 31 2018, see Clean Cooking Alliance (2018a).

[53] The Energy Progress Report was formerly known as the Global Tracking Framework and is today produced in a joint effort of the IEA, the International Renewable Energy Agency (IRENA), United Nations Statistics Division (UNSD), the World Bank, and the World Health Organization (WHO).

[54] See http://www.ecreee.org/Project/wacca for more information. Technical partners of the initiative include the GACC, the Austrian Energy Agency, the GIZ and a couple of NGOs.

ECOWAS countries, but also selected East and Central African countries, aim at very widespread use of LPG, e.g., Cabo Verde, Nigeria, Angola, Gabon or Tanzania (van Leeuwen, Evans & Hyseni, 2017).

Governments of these countries take this initiative to meet the SEforALL goal and SDG 7 of universal access to modern energy – reflected as part of the countries' SEforALL Action Agenda – but also to protect forests and foster economic development (Bruce, Aunan & Rehfuess, 2017). The Global LPG Partnership is assisting some countries to craft policies and plan investments in order to increase LPG use (van Leeuwen, Evans & Hyseni, 2017). In Cameroon, Ghana and Kenya, this support implemented by the Global LPG Partnership was delivered through the Clean Cooking for Africa Programme of the KfW Development Bank, funded through the European Union-Africa Infrastructure Fund (EU-AITF). In two of the three countries, planned support was likely to include investments into LPG infrastructure (Bruce, Aunan & Rehfuess, 2017), but the resources potentially available to create a corresponding investment fund expired when EU-AITF was discontinued and transferred into a new financial facility, whereas any pending projects were not transferred to the new facility (personal communication KfW representative). [55]

Important LPG subsidy programs that succeeded in the switch of major population parts to LPG are/were running in India since 2016 (see Chapter 7), in Peru since 2010 (Pollard et al., 2018), in Ecuador since the 1970s (Gould et al., 2018)[56], in Indonesia 2007-2012 (Thoday et al., 2018), and (to some extent) in Ghana and Senegal. The earliest initiative to promote LPG was Brazils largescale national program from the end 1970s to end 1990s (Lucon, Coelho & Goldemberg, 2004). Consistent fuel stacking remains an issue in many of these countries though and where LPG consumption is heavily subsidized, their high fiscal burden, and problems of diversion for other uses and smuggling remain substantial challenges to address. Remarkably, the lion's share of programs promoting LPG, e.g., in India or Indonesia, is initiated and financed by national governments themselves.

The discussion above showed that development banks and international initiatives appear to have started to embrace LPG in recent years, alongside with other clean fuels (e.g., Putti et al., 2015). The renaming of the *Global Alliance for Clean Cookstoves* to the *Clean Cooking Alliance* in 2018 might be a further indicator of this broader tendency. Additionally, researchers and practitioners are increasingly interested in analytical approaches that consider both health and climate benefits. More specifically, they aim to understand how LPG and advanced IBCs could be best combined to maximize benefits across SDGs in countries where the exclusive use of clean fuels is not a realistic scenario in the nearest future (Rosenthal et al., 2018; Serrano-Medrano et al., 2018).

[55] This information is part of self-collected survey- and interview data from key representatives in the clean cooking sector that is used for the study presented in Chapter 6. All methodological details are provided there.

[56] Due to different factors, including the high fiscal burden from LPG subsidies and increased availability of electricity from hydropower, Ecuador's Government has launched a major induction stove program (PEC) to reduce the demand for LPG in 2014 Gould et al. (2018).

5.7 Conclusion

The historical outline presented here has illustrated, first, that the prevailing understanding of residential energy use in resource-poor settings has evolved significantly over the past decades and, second, that there is now much greater international coordination of efforts to improve access to clean and efficient energy for cooking.

The longest-pursued and most popular approach in development cooperation has been to introduce improved cookstoves for biomass and other solid fuels. That said, in view of the evidence that electricity or clean fuels (rather than improved biomass stoves) are required to bring harmful air pollutants below WHO limits in the long term (see 4.1.2), international support for these fuels has somewhat increased since approximately 2012. Yet, the academic and grey literature reviewed in this chapter suggests that this support remains below the efforts that could be expected given the scope of clean fuels and stoves to reduce the global burden of disease from cooking. Meanwhile, national governments have promoted widespread access to LPG for several decades, most recently through large-scale programs in India and Indonesia (GBD 2016 Risk Factors Collaborators, 2017; Gould & Urpelainen, 2018). Hence, among the options achieving high reductions of HAP, LPG has seen the greatest historical and current scale-up activities and is seen by many as an important transition fuel (Goldemberg et al., 2018; Quinn et al., 2018).[57]

In view of the situation described above, public health scholars and institutions have been calling for a stronger focus on electricity and modern fuels (Bruce et al. 2015; Smith and Sagar 2014). Some of them note that stove programmes have often cited health benefits as an important goal, but were primarily oriented towards other gains, especially climate change mitigation, leading to a neglect of health-centered interventions (Goldemberg et al., 2018; Rosenthal et al., 2018; Smith & Sagar, 2014). In view of the rather limited climate benefits of IBCs (see 4.1.1), some proponents of LPG even argue that the household energy agenda has been compromised by the constraints arising from a narrow definition of sustainability, focusing on renewable fuels only (Goldemberg et al., 2018).

It appears, therefore, that there are very different views among donors on how to set priorities in the field of household energy. Hereby, a range of further considerations beyond the benefits of improved energy access might motivate the orientation of development programs. Given the potentially significant developmental consequences, we need a better understanding of the direction in which the sector is heading and of the interests that lie behind donor priorities. Chapter 6 will therefore examine the ideological, political and economic factors underpinning donor strategies in a theoretical and empirical analysis of the sector.

[57] This is mainly because upscaling and deployment in rural areas are considered relatively easy for LPG. Ultimately, the goal may be universal access to electric stoves, ideally powered by renewable energy, as noted by Goldemberg et al. (2018).

6 THE POLITICAL ECONOMY OF IMPROVED BIOMASS- VERSUS LPG STOVES

6.1 Introduction

As discussed in previous chapters, access to efficient and clean cooking facilities offers progress towards multiple objectives of sustainable development, including a reduction of poverty and the global burden of disease, environmental and climate protection, and enhanced local development and gender equality. A recent debate highlights the relationship between these objectives (see 5.7), notably potential trade-offs between health and climate benefits (Cameron et al., 2016; Goldemberg et al., 2018).

In this context, despite the pressing need to capitalize on the benefits from access to clean cooking facilities, we have a limited understanding of how the priorities of key actors in this sector are evolving and why they differ so much. Proponents of LPG as a clean fuel argue, for instance, that climate-oriented goals strongly influence the discourse and actions of international sustainable development, leading to a focus on emission reductions through the promotion of improved cookstoves and renewable biomass (Goldemberg et al., 2018). Yet, there is little empirical evidence on whether and by which mechanisms climate policy influences development cooperation in the field of household energy.

This study therefore aims to identify and explain the different positions of donors on clean cooking interventions by exploring what is shaping their priorities. The analysis focuses on the promotion of LPG versus IBCs, which have been the two globally dominant options in government programs and development cooperation and which are at the heart of the debate on health vs. climate benefits from cooking interventions in the residential sector.[58] Since clean cooking is a crosscutting issue, very diverse actors are addressing it from their respective perspective. Moreover – similar to aid allocation in general – political and economic factors may underpin preferences for certain technologies.

I thus seek to examine how priorities in clean cooking programs are influenced by economic incentives, political interests, and power, which are in turn shaped by institutional structures and norms. My analytical framework is mainly based on a rational choice approach and draws on findings from the political economy of aid and the climate finance literature.

[58] However, as mentioned before, other clean fuels and appliances, e.g., those powered by electricity or biogas, are becoming increasingly relevant.

The empirical analysis is informed by the academic literature on clean cooking interventions and climate finance, policy documents and the interpretation of these documents. I complement and cross-validate this evidence with self-collected data from a survey among representatives of key organizations in the sector and from in-depth interviews with key informant experts.

In the remainder of this chapter, I will proceed as follows. In 6.2, I present the analytical framework and formulate expectations about how its elements and their interactions explain allocation priorities in the sector. In the empirical analysis in 6.3, I first examine each element of the framework in turn to assess how it has shaped donor priorities. More specifically, I study the interplay between the institutional arrangements and the organizations, in particular how institutional characteristics structure the behaviour of organizations active in the sector, taking into account their roles, interests and ideas. I subsequently present results from an expert survey and from personal interviews, which will serve to triangulate the findings from the first part of the study and provide evidence on current aid allocation trends in the sector. Section 6.4 concludes the chapter with a critical discussion of the results.

6.2 Analytical framework

This section specifies the key elements of the analytical framework and develops a theoretical argument on how they interact in order to explain donor priorities in the clean cooking sector. The conceptual basis of my analytical framework is primarily inspired by rational choice institutionalism. The framework further draws on findings of the literatures on the political economy of aid and on climate finance, which are broadly related to the topic.

6.2.1 Actors

Actors in the context of this analysis are broadly defined as all organizations involved in the promotion of clean cooking fuels and technologies. Their activities are very diverse and include, amongst others, project planning and implementation, advocacy work and the production of appliances. The individual organizations are sometimes part of higher-level initiatives/organizations or make financial contributions to these organizations' activities. Decisions regarding resource allocation to clean cooking interventions are made at both levels.

Donors have a central role to play, as their financing has a decisive influence on the implementation and orientation of interventions. Bilateral and multilateral donors, through their substantial financial contributions and their intermediary role respectively, typically have a particularly important part to play.

Regarding the actors' resource allocation to specific technologies, I expect that those with a mandate directly linked to either public health or climate change mitigation base their behaviour on this mandate, i.e., opt for clean fuels or biomass cookstoves respectively. Apart from organizations with particular interests, there are a number of actors, which have a general development mandate, such as non-governmental aid organizations, national development agencies and development banks. They can be expected to be interested in the integrated possibilities of promoting sustainable development with cookstoves, including their climate and health benefits, and beyond that, the promotion of the local economy, gender equality and other social benefits. These actors' resources may be used to support both IBC and LPG interventions.

However, bilateral and multilateral donors do not simply allocate resources according to mere technocratic criteria. The aid allocation literature examining how official development assistance (ODA) granted by bilateral donors is allocated to different developing countries shows, for instance, that aid is often allocated according to donor interests instead of recipient need (e.g., Berthélemy, 2006) and that aid allocated based on donor interest is less effective (Kilby & Dreher, 2010). I therefore expect donors' allocation decisions to be influenced by economic incentives and (political) norms, which result mainly from the institutional framework in the clean cooking domain, as discussed in the following section.

6.2.2 **Institutions**

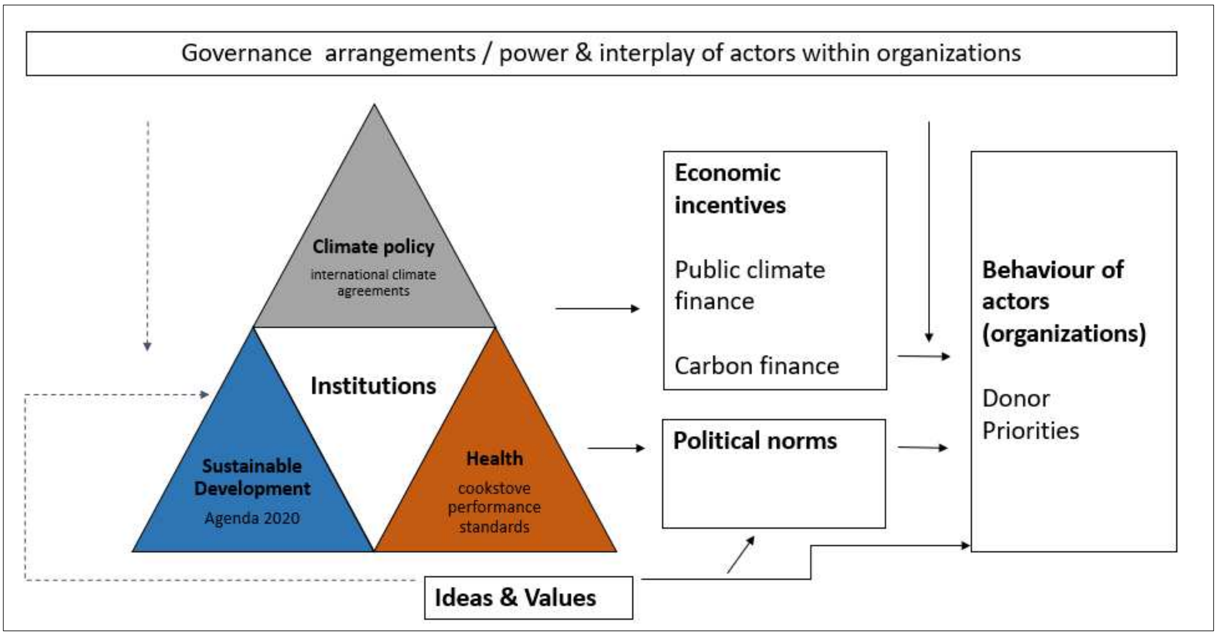
In political analysis, there is now broad consensus that "institutions matter" because they constrain but also enable actions by states and other actors (e.g., Hay, 2002). Following a widely accepted definition, *institutions* can be understood as "the rules of the game" (North, 1990), with organizations and individuals (in this chapter *actors*) as the players. These rules comprise regulative and normative elements and shape human exchange – economically, socially and in political life. The rules can relate to formal institutions (such as legal systems, regulations, and standards) or informal institutions (like social norms or cultural practices). In political economy approaches that draw on public choice theory (Mueller, 2003), the critical role of institutions is to provide incentive structures: institutional characteristics define the incentives that structure the behavior of self-interested, rational actors.

Of course, institutions or institutional arrangements can evolve and change in the long-run and agency and politics are required to build and maintain institutions (e.g., Leftwich & Sen, 2011). This is also true for the sets of rules and norms considered in this chapter. These have changed and developed considerably, among other things through negotiations between the actors and in response to new scientific findings. However, the focus of this paper is not on questions of the emergence of these norms, but on their impact. In particular, the aim is to examine how the institutional framework, as it has been in place since about 2015, shapes donor priorities today (2020) and in the coming years. Regarding this period of not much more than a decade, it is reasonable to assume that the essential characteristics of the relevant institutional framework remain in place. Therefore, in the context of this analysis, I will interpret institutions as essentially exogenously given.[59]

[59] That said, there will be occasional references of the (long-term) shaping and changes in institutional settings, however, they are not empirically analyzed in a systematic way.

Figure 5 depicts the basic features of the analytical framework. The figure in the left part illustrates three interrelated policy areas in which more or less formal institutions with relevance for the clean cooking sector exist and indicates the major institutions on the global level in these areas. First, the area of poverty reduction and development with the **UN's 2030 Agenda for Sustainable Development**, which should ensure the promotion of an economically, socially but also environmentally sustainable future. Second, the area of public health, in which the efforts to reduce household air pollution are increasingly institutionalized in the form of **guidelines for indoor air quality and performance standards for cookstoves**. Third, the field of climate policy, in which **international climate agreements**, notably the Kyoto Protocol in 1997 and the Paris Agreement in 2015, have led to international and national emission reduction targets and new financing mechanisms.

Figure 5 Theoretical framework for the analysis of donor priorities



Source: Author's own illustration.

All of these institutions potentially influence development aid in the household energy sector by setting *(political) norms and standards*, but also through *economic incentives* (see Figure 5). How strong the influence of these sets of rules is will depend on how stringent they are and on the extent to which they provide economic incentives in favor of a specific technology.

Of the sector's relevant institutional arrangements, it can be assumed that those in the field of climate policy are particularly important, not only for actors with a direct link to climate protection, but also for bilateral and multilateral donors. First, they imply binding procedural commitments concerning emission reduction efforts and payments and second, they have led to the construction of financial mechanisms that are likely to affect donor decisions concerning energy access programs. The following section discusses why and through which mechanisms these finance instruments, notably public climate finance and carbon finance, may affect priorities.

6.2.3 Economic incentives: Climate finance and carbon finance

Due to the growing links between climate and development policy, notably since the Kyoto Protocol, climate-related development finance has increased significantly, both in absolute and relative terms: Climate-related bilateral aid reached $ 27 billion in 2017. Its share grew steadily, from less than 10 % in 2007/2008 (Tara Shine & Gisela Campillo, 2016: 14) to 20 to 21 % in the years 2014-2017 (OECD, 2019: 27). In multilateral finance, climate-related comittments accounted for an estimated 28 % of all commitments, up from 20 % in 2013 (ibid.).[60]

In the context of international climate change negotiations, climate finance describes financial flows from developed to developing countries to fund climate change mitigation or adaptation activities. Industrialized countries decide on the climate-related support and report it as as part of their ODA to the OECD. In the international climate change negotiations, financial commitments by developed countries only qualify as climate finance if they represent investments beyond usual development aid, i.e., they are 'new and additional'. However, as various experts have pointed out (e.g., Michaelowa & Michaelowa, 2007; Stadelmann, Roberts & Michaelowa, 2011), a substantial part of the funds reported by the industrialized countries as climate finance cannot be regarded as new and additional. This gives rise to concerns that the financial resources dedicated to tackling climate change are being diverted from other development priorities.

The reporting on climate aid is also driven by political factors: Michaelowa & Michaelowa (2011) show that donor countries over-report the climate relevance of their development activities and that aid projects are more likely to be wrongly coded as climate projects if the parliament is favorable to climate change action.

Due to the climate mitigation potential of cleaner and more efficient cooking technologies, interventions to promote them may be funded through climate finance. Hence, donor countries engaged in the promotion of household energy access are likely to provide assistance for these activities through climate finance, as they can use restricted public resources to combine their climate finance commitments with general development assistance. This in turn can affect allocation decisions for household energy projects (referred to as *economic incentives* in Figure 5).

Scholars emphasize that climate change mitigation aid should be allocated according to a logic that does not follow that of traditional ODA because it is spent on global public goods (Bagchi, Castro & Michaelowa, 2016). In this context, Michaelowa & Michaelowa (2007) found that aid-financed emission mitigation projects only contribute to the central development objective of poverty reduction to a limited degree, while other types of projects are expected to

[60] These are OECD estimates. As there are no internationally agreed methods for tracking climate financing, further accounting and reporting practices exist, which has led to conflicting statements on climate financing. See, e.g., Weikmans & Roberts (2019) for a discussion.

be much more effective. Overall, the discussion in this strand of literature suggests that integrating development and climate financing can lead to suboptimal solutions from a development perspective.

In the context of climate policy institutions and cooking energy, it is equally important to consider carbon finance. I refer to carbon finance as financial mechanisms that are designed to reduce climate-impacting emissions by issuing or auctioning a limited number of corresponding emission rights that can be traded on carbon markets. Carbon finance provides a source of funds for household energy interventions. Since carbon finance instruments are built around the primary goal of offsetting greenhouse gas emissions, the way carbon-offsetting mechanisms for cleaner cooking technologies are designed is likely to incentivize the use of technologies based on biomass (see *economic incentives* in Figure 5). The validity of these theoretical expectations will be assessed in the empirical part of this study, by investigating the relevance and design of climate finance and carbon finance mechanisms in the context of clean cooking interventions.

6.2.4 **Governance arrangements and power**

Another important factor to be considered when studying donors' allocation strategies is the influence of individual actors within the organization (see *governance arrangements* in Figure 5). The literature on the political economy of aid demonstrates that the lending patterns and operational characteristics of multilateral development banks and other international finance institutions are influenced by individual donors (e.g., Dreher, Sturm & Vreeland, 2009; Kilby, 2006) and that the governance arrangements involved are a relevant mechanism in this context (e.g., Humphrey, 2014).

With regards to bilateral donors, the general literature on public bureaucracies suggests that actors within governments have an important influence on political decisions (Kettl, 2009). More specifically, regarding decisions on climate finance, Peterson & Skovgaard (2019) highlight that funding activities through climate finance often implies the involvement of several ministries with different priorities in the contributing country. This observation is likely to be true for energy-access related activities in general. Peterson & Skovgaard's research shows that ministry involvement affects the selection and allocation of climate finance to recipient countries. Pickering et al. (2015) studied the role of inter-agency dynamics (especially between development, environment and finance ministries). They found that national development agencies maintain substantive control over the implementation of the donor's climate finance approach. Nevertheless, the ministries of environment and finance have a significant role to play, and frequently have diverging agendas. Important issues on which ministries disagree are the distribution (I) between mitigation and adaptation and (II) among geographical regions. While development agencies tend to favour higher expenditures for adaptation measures more in line with their development objectives, the ministries of environment favour mitigation spending geared towards achieving environmental protection targets.

Hence, regarding donors' resource allocation to household energy projects, the literature discussed here tends to suggest that the involvement of other ministries will reduce the weight of health objectives. I expect that this effect is particularly strong if the intervention is funded through climate-finance.

In order to identify key actors, power structures and economic incentives, the empirical part of the study will especially focus on examining by whom, and through which channels projects in the sector are financed and how these instruments are designed.

6.2.5 Ideas and Values

When analyzing how agents act within their structural and institutional context, we also need to take into account the role of *ideas* (e.g., Hay, 2002), which include, amongst others, world views, knowledge and learning, prejudices or the interpretation of events or contexts. Ideas are important for understanding political outcomes and decisions as they affect how problems are understood and solutions are defined and communicated, shape how agents understand the world and what they find important and provide motivations and ideals (Béland & Cox, 2011).

Figure 5 illustrates the role of ideas in the analytical framework I use to study the clean cooking sector: actors in the sector draw on their ideas and interpretations in order to construct their interests, i.e., their *preferences* regarding policy options. Based on these preferences, they allocate aid in the sector in a way that is optimal for them, given the constraints set by the institutional framework.

Ideas exist on several levels. Following Schmidt (2008) we can distinguish between ideas on the level of (I) policies, (II) programmes and (III) philosophy to analyze how they shape donor priorities, whereby ideas on the policy level are guided by those on the programmatic and ideological or philosophical level. At the programmatic level, the knowledge within donor organizations or their assessment of the relevant context may influence the utility that donors expect to derive from different policy options respectively and thus their preferences in this respect. At the same time, decision-makers in donor countries and other actors also hold ideological attitudes, or values, (i.e., ideas on the ideological/philosophical level) that affect their preferences, e.g., by guiding ideas on the programmatic and policy level.

I assume that donor priorities with respect to household energy projects are informed mainly by the following ideas. On the *ideological level* – i.e., rather slowly changing ideas that are closely linked to people's worldview – I expect notably the importance of climate protection, the understandings of sustainability, and ideologies and approaches to development cooperation to play a role. Ideas surrounding the meaning of development and the role of development cooperation have evolved over time (e.g., Easterly, 2007; Evans & Stallings, 2016; Thorbecke, 2008), and aid decisions, e.g., the mainstreaming of climate change into development cooperation, may be shaped by the prevalent approach to development (e.g., Gupta, 2009).

At the *programmatic level*, I expect that differences in the assessment of scientific findings on the environmental, health and social impacts of clean cooking alternatives will shape preferences for promoting specific technologies. More specifically, the fact that comprehensive knowledge about the effectiveness of different alternatives in terms of reduced indoor air pollution and climate-warming pollutants has become available rather recently may be a potential explanation for the continued focus on IBCs. In addition, the opportunities and barriers associated with the implementation of clean cooking interventions in a specific (country) context may be assessed differently, leading to diverging views on its prospects.

While this analysis focuses on the direct link between ideas and the priorities of donor countries, institutions (rules) and the various structures within the sector that constrain a donor's strategy are – in the long term – shaped, underpinned, interpreted or changed through their interaction with ideas. Bilateral donors and other actors may for example attempt to shape the formation and transformation of institutions like international climate agreements according to their attitudes, by exercising their voting rights as members of international organizations. Figure 5 illustrates this mechanism with dashed lines, but it is not the focus of this work.

6.3 Empirical analysis of the clean cooking sector

Chapter 5 traced how the clean cooking sector developed over time, reflecting the prevailing perceptions of the subject. The historical outline also described the emergence of key institutions and governance arrangements in the sector. In the empirical part of this chapter, our focus is on how the *current* design of these institutions and other framework conditions shapes donor priorities in the sector, in their interplay with the other elements of the analytical framework.

The empirical analysis therefore starts out with examining the sector's key institutions and governance arrangements in detail, to understand how they can limit or enable decisions of central actors, and incentivize specific actions (6.3.1). An important complement to this is the investigation of the financing structure of the sector (6.3.2). Identifying from which sources and through which channels funding for clean cooking projects is provided and which governance structures shape the decision-making processes behind it, offers information about the key donors, i.e., powerful actors in the sector and their current priorities, as well as on the relevance of different financial instruments. By examining how financial instruments are structured, we also understand the (economic) incentives they provide for action. The first part of the empirical analysis concludes with an overview of the actors in these groups with their respective mandates, and combines the findings of the previous sections to explain priorities in the sector (6.3.3).

The second part complements and validates these findings by information from self-collected data on actual resource allocations, on views that representatives of key organizations in the sector hold regarding the clean cooking issue, and on the beliefs and values underpinning these views (6.3.4).

6.3.1 The role of institutions

The analytical framework outlined three main policy domains that address the problems associated with traditional cooking from their respective perspectives, yet with significant overlaps: global public health, climate/environment, and the aid sector. As traced in Chapter 5, international coordination in all of these domains has evolved considerably after 2010, resulting in new transnational networks and initiatives, objectives that are more stringent, potentially stronger instruments, clearer definitions and increasingly standardized measurement methods for evaluating target achievement. Thereby, some institutions and governance structures were created that explicitly refer to clean cooking promotion. Others, particularly those related to climate change mitigation, developed independently as general objectives and standards in the area. They may be equally relevant to the clean cooking sector though.

Sustainable development and energy access

In 2011, the recognition of the need to act on energy poverty in a coordinated manner within the UN system led to the launch of the SEforALL initiative (see 5.5). SEforALL aims to achieve universal access to modern energy services (including electricity and clean cooking equipment), doubling the global rate of improvement in energy efficiency, and doubling the share of renewable energy in the global energy mix. The initiative can be best described as a global platform that aims to bring together a large number of partners (governments, the private sector, and development banks among others) in order to catalyze action on sustainable energy. An important channel through which SEforALL implements its initiative in Africa is known as the country action process, which involves a series of steps by national governments supported by SEforALL partners: the steps range from the assessment of existing conditions over the definition of National Action Agendas (long-term objectives) to the promotion of investment opportunities (SEforALL, 2018). Essentially all national action agendas formulate targets for both a substantial increase in clean cooking fuel (in particular LPG) use as well as in improved biomass stoves.[61]

The SEforALL goals link closely to the Paris Climate Agreement and the SDGs (see also 5.5), whereby the SDG 7 targets essentially mirror the SEforALL goals.[62] [63] The indicator used to track progress towards the energy access target (SDG 7.1) related to cooking is the "proportion of population with primary reliance on clean fuels and technology" (UN, 2020). For that purpose, *clean* is defined by emission targets and fuel recommendations according to the WHO guidelines for indoor air quality (WHO, 2014) that focus on reducing the level of pollutants as much as possible. Similar to performance targets for stoves discussed subsequently, such definitions could raise donor awareness of the cleanest fuels and technologies.

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[61] See Action Agendas for different countries here: https://www.se4all-africa.org/seforall-in-africa/country-actions/action-agenda/

[62] Except for the renewable energy share where SDG 7 calls for a vaguer "substantial increase" rather than a "doubling."

[63] Regarding climate action, in the SDGs, the UNFCCC is acknowledged as the primary forum for negotiating the coordinated response to climate change. The associated targets of SDG 13 concentrate on the integration of climate change policies into national strategies, policies and planning, awareness-raising and institutional capacity, amongst others.

The SDGs and the platform organization SEforALL moreover assume important coordination functions and draw attention to the issue of energy access in general, which help mobilizing some resources among donors.

However, they do not involve binding implementation requirements at the national level or financing commitments for the states and actors involved. Hence, their influence on the decisions of major actors in the sector is limited.

Global public health

Given the enormous global health burden of air pollution, public health institutions have been concerned with the consequences of residential energy use for air quality for many years (Maynard et al., 2017). It was not until 2005, however, that the WHO published separate and revised guidelines for indoor air quality (WHO, 2006b) and standards for cookstoves began to be discussed at expert meetings. The US environmental protection agency's Partnership for Clean Indoor Air (PCIA) and later the Global Alliance for Clean Cookstoves (in which PCIA was integrated) initiated and coordinated the development of such standards within the cookstove community. Starting with a consensus on a simple temporary rating system that defined tiers of performance in terms of $PM_{2,5}$ and CO emissions, fuel efficiency, indoor emissions and safety 2011, interim performance guidelines were adopted in the International Workshop Agreement by the International Organization for Standardization (ISO) in 2012.

They were further developed into a final series of ISO standards on harmonized laboratory testing protocols, sector-specific vocabulary and voluntary targets for cookstoves and were published throughout 2019 (Clean Cooking Alliance, 2019b; ISO, 2019). The targets address the following indicators: thermal efficiency, emissions of particulate matter and of carbon monoxide, safety and durability. The results of the laboratory tests are evaluated for each indicator along six tiers (or levels), from 0 for open fires or the simplest stoves up to 5 (highest performing stoves) (Clean Cooking Alliance, 2019b). In addition, numerous testing centers to compare stove qualities have been established across the globe (GACC, 2017; Putti et al., 2015).

The development of performance standards for cooking devices and fuels hence evolved along with and was underpinned by the scientific evidence on the subject, which has only gradually become available in the public health literature (see 4.1.2).

Performance standards aim to serve as a guideline for donors, investors, policy-makers, cookstove manufacturers and consumers alike. Given that they are now formalized at the highest international level, cookstove performance standards provide an important frame of reference for the allocation decisions of donors. Especially in the development and deployment of stoves, access to clean stoves and fuels is now gaining importance compared to technologies that are only 'improved' in one way or another.

International climate policy

The Paris Agreement passed in 2015 obliges all states to reduce their greenhouse gas emissions. Parties further agreed to work towards an increased ability to adapt to the negative impacts of climate change, foster climate resilience and promote low greenhouse gas emissions development.

The Agreement imposes a legally binding obligation for all countries to submit their nationally determined contributions (NDCs), i.e., their domestic emission reduction plan, every 5 years. Industrialized countries are urged to set absolute economy-wide emission reduction targets, whereby emission reductions abroad can be taken into account as a partial fulfilment of the targets. The attainment of targets cannot be enforced and requires that countries hold each other accountable for setting ambitious emission reduction goals and for making strong efforts to achieve them. However, the commitment of states to submit their NDCs and to pursue domestic mitigation actions by integrating climate change measures into national policies, strategies and planning, and reporting on the attainment of targets is legally binding.

In the run-up to the Paris Agreement, clean cooking was widely discussed as an important component of mitigation efforts that also addresses the needs of the poor. Numerous low-income countries considered cooking with wood fuel or charcoal as a factor for mitigation and included its promotion in their NDCs. The provision of support to the installation of improved cookstoves in low-income countries was also a relevant instrument for industrialized countries to meet a part of their emission reduction commitments, through the Clean Development Mechanism (CDM)[64] under the Kyoto Protocol and very likely as part of future collective arrangements between countries under Article 6 of the Paris Agreement.[65]

International financial institutions, donor countries and national governments have repeatedly stated that they aim to make financial flows consistent with a pathway towards low greenhouse gas emissions and climate-resilient development. The international climate agreements oblige developed-country parties to support developing countries in their emission reduction and adaptation measures. In Paris 2015, parties agreed that greater financial support for climate action in developing countries is required. Developed-country parties reaffirmed their commitment to jointly mobilize $100 billion yearly by 2020.

Today there is a complex landscape of international financial flows for climate mitigation and adaptation action from industrialized countries to developing countries. Climate finance is channeled through the financial mechanisms established under the UNFCCC (e.g., the Green Climate Fund), a number of bi- and multilateral climate funds (e.g., the Climate Investment Fund), development agencies, or the private sector and it comes as ODA, 'new and additional' public climate finance or in the form of emission reduction certificates through the carbon markets. All of these instruments have created improved opportunities to finance projects in developing countries that aim to reduce emissions and promote sustainable development, including by promoting cleaner and more efficient cookstoves.

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[64] The CDM is a project-based mechanism under the Kyoto Protocol (Article 12). Under the CDM, Annex I countries can buy Certified Emission Reduction (CER) units from CDM emission reduction projects in developing countries and meet a part of their emission reduction commitments under the Kyoto Protocol by doing so (Carbon Trust 2009, 14).

[65] Peru and Switzerland are for instance planning an agreement on Art 6 cooperation with a large-scale cookstove project as a first mitigation activity. For more information see: https://www.international.klik.ch/resources/Joint_Statement_by_Peru_and_Switzerland_on_Article_6_Cooperation_Paris_.pdf

Making financial flows consistent with a pathway towards low greenhouse gas emissions moreover implies the reduction or elimination of existing production and consumption subsidies for fossil fuels, with potential implications for donors, as discussed below.

Fossil fuel subsidy reform as a global norm

As discussed in Chapter 2, subsidies to the consumption and production of fossil fuels are associated with detrimental environmental, economic and social effects. Against this background, fossil fuel subsidy reform has recently climbed up the climate policy and development agenda with international organizations making considerable efforts to push for reductions (Rentschler & Bazilian, 2017). Chapter 2.3 traced the emergence of fuel subsidy reform as a political norm, with repeated commitments to reform by a range of multilateral conventions and with strong support from international organizations like the World Bank, the IMF, the IPCC, the UN and the IEA, on behalf of climate mitigation and sustainable development.

Reiterating from 2.3, the issue fully entered the mainstream development agenda when subsidy reform was included in the SDGs, as sub-goal Goal 12.c:

> Rationalise inefficient fossil-fuel subsidies that encourage wasteful consumption, […][while] taking fully into account the specific needs and conditions of developing countries and minimizing the possible adverse impacts on their development in a manner that protects the poor and the affected communities. (United Nations, 2015, p.19)

This wording reflects a balanced view that highlights the importance of fossil fuel subsidy reform in mitigating climate change while taking into account the needs of low-income countries. In the case of LPG, targeted consumption subsidies for poor households who cannot afford it otherwise have quite different implications than other fossil fuel subsidies do, from a development, but also environmental perspective.

In terms of support for low-income countries to remove energy subsidies, the efforts of the donor community were essentially limited to the provision of analytical work in support of international diplomatic efforts (McCulloch, 2017) (see also 2.3). Yet, the national climate strategies of bilateral donors and their repeated calls to eliminate global fossil fuel subsidies raise expectations for policy coherence, such that development cooperation action takes account of and supports these objectives on the national level. Hence, for donor countries, differentiating between 'good' and 'bad' fuel subsidies and supporting the first while reiterating calls to eliminate the second is a political balancing act that their governments may not desire attempting. Therefore, while LPG subsidies are not generally incompatible with the SDGs, actively providing support to its widespread use as a clean cooking technology is a strategy that donors are likely to find difficult to justify politically, since LPG is a fossil fuel. We will be able to scrutinize the validity of these statements using the data from the expert survey and the interviews in 6.3.4.

Hence, the institutions of international climate policy have a strong potential for shaping the allocation of international support to promote residential energy access in low-income countries through multiple mechanisms. First, politically, since development policy is expected to support the emission reduction targets to be achieved domestically and abroad, and should be consistent both with political norms like fuel subsidy reductions and with the public interest. Second, economically, because the instruments of climate-related finance may provide constraints and incentives to invest in certain projects. The analysis thereof constitutes a part of the following section. In that section, the financing structure of the sector is examined in more detail. This offers further information about the key donors in the sector and their current priorities, as well as the relevance of different financial instruments. By examining how these are structured, we also understand the (economic) incentives these instruments provide for action.

Another aspect that will probably be relevant in the context of international climate negotiations, but is not discussed here, is the increased focus on net zero emissions. It will make it difficult to justify major investments in activities that lead to *low* but not *zero* emissions. In the area of household energy, only approaches based on renewable energies such as solar cookstoves would then be viable.

6.3.2 **Financing structure: key sources and incentives**

Finance for residential clean cooking contributes important information on who provides support, through which instruments and channels and for what type of uses and activities (the latter is discussed in section 6.3.4). Programs to promote access to clean cooking technologies and fuels have been financed through a number of public and private sources in the past. The consolidation of data on clean cooking finance transactions is extremely challenging, though. The best available analysis is provided by SEforALL based on data on financial flows to residential clean cooking. The reporting is focused on 20 countries in which nearly 80 % of those individuals without access to clean energy live, so-called high-impact countries (SEforALL & CPI, 2019). The analysis uses project-level data from the OECD Development Assistance Committee (DAC) Creditor Reporting System, the Alliance's self-collected data (from its members) on financing raised from cookstove and fuel companies, data from the World Bank Group, the IJ Global data source, and surveys among impact investors and philanthropic foundations. However, through SEforALL's tracking exercise, a number of important data gaps were identified, which puts limits on the reliability of the analysis.[66] The total of trackable finance varies strongly across the years, namely between $32 and $117 million (2015-16) in the high-impact countries. The amount actually spent is certainly higher, particularly if national government spending is considered.[67] However, these are still very small amounts as compared to the estimated $4.4 billion of yearly investments required to achieve universal access to clean cooking by 2030 (SEforALL & CPI, 2018: 51). This confirms that the clean cooking sector still largely

[66] For instance, the available information on large transactions for LPG storage and filling plants is limited, as these transactions are typically made upstream. Moreover, carbon finance transactions are not explicitly expressed in the collected data. Therefore, it is very likely that the data covers them only partially or not at all. Domestic public finance and "south-south" financing are further data sources for which major data gaps exist and consequently, these dimensions are likely to be underrepresented in the analysis, see SEforALL & CPI (2018: 39).

[67] To put these investments into perspective: Between 2016 and 2019, India's government already spent at least $1.8 billion (1600 Indian Rupees for 80 million households) on the "Pradhan Mantri Ujjwala Yojana" (PMUY) program. PMUY aims to provide widespread access to LPG by providing a one-time subsidy and an optional loan to cover the initial upfront costs. See Chapter 7 and http://www.pmujjwalayojana.com/ for more information.

lacks the major investments needed to scale-up clean cooking programs (IEA et al., 2019: 56; SEforALL & CPI, 2019). For the time being, cookstove programs hence have to compete for very limited resources.

Finance provided through official development assistance and climate finance

The SEforALL tracking aims to provide information on the providers of clean cooking finance and on what types of assets are financed. Due to the data and methodological complexities associated with the analysis of clean cooking, certain sources of finance are not captured well, though, particularly domestic public funding and domestic private investments. Therefore, the SEforALL report does not allow drawing reliable conclusions on the share that different providers contribute to clean cooking finance and on how domestic actors allocate resources to different types of assets.[68] However, international donors and multilaterals including climate funds are key providers of finance for clean cooking projects. Donor countries hereby channel their contributions to clean cooking projects through multi-donor and single-donor funds and programs, in particular through EnDev, the Alliance, development banks and through climate finance facilities (SEforALL & CPI, 2018). As they provide the lion's share of funds for these major programs, donor countries are key actors in the international efforts to promote clean cooking. Apart from public assistance, further financial support comes from private foundations.[69]

In view of the importance of climate finance for the clean cooking sector, its instruments deserve closer examination. After a few further remarks on public climate finance, the focus here is on the carbon markets.

Public climate finance is becoming increasingly important in global climate governance and consequently, global climate finance flows and the commitments of donor countries have increased significantly (CPI, 2019). Major climate funds are the Climate Investment Funds (CIF), which are administered by the World Bank and implemented in partnership with regional development banks like the African Development Bank (AfDB), the Asian Development Bank (ADB) and the Inter-American Development Bank (IDB). A newer, very important fund is the Green Climate Fund. Established in 2010 by the UNFCCC, it launched its first resource mobilization in 2014. As mentioned above, the international community aims to raise at least $100 billion worth of new and additional resources per year and channel them to projects aiming to lower emissions and increase climate-resilience in low-income countries. The financial capacity of the fund, which is to be the main climate-financing instrument in the future, has been built up only slowly, however.

[68] The large-scale government programs of India and Indonesia to promote LPG are for instance not represented.

[69] See SEforALL & CPI (2019: 77–78) for a visual portray of providers, channels, uses and other aspects of clean cooking access financing in 2017. Note that this work focuses on the situation in development assistance. Private investments and the like are therefore not considered here.

Nonetheless, contributions to public climate financing are increasing. Funding household energy projects via climate financing is thus attractive for financially constrained bilateral donors, albeit the relevance of this strategy in practice has to be verified by evidence from the expert interviews. The obvious focus of climate financing on low-emission interventions, which is further strengthened by the involvement of environmental and other agencies in the allocation of funds, increases the likelihood that household energy projects are geared towards emission reduction and therefore focus on renewable energies and energy efficient biomass technologies such as IBCs or biogas.

A related, historically important source of financing for clean cooking projects has been carbon finance through verified emission reductions (carbon credits). Which role these transactions (of which only few are included in the SEforALL tracking) play and how the design of carbon market instruments might affect the sector, is discussed below.

Carbon finance

Relevance of carbon finance as a funding source

Both the official regime under the Kyoto Protocol's CDM and voluntary carbon market schemes have played important roles in providing startup capital for clean cooking projects from 2007 onwards (UNFCCC, 2007).[70] Under the CDM, even though project development activity has increased over the years, project registrations and credits issued have been limited. Therefore, IBC carbon offset projects do as yet not constitute a relevant fraction of the overall volume of credits generated by individual project activities (Bailis et al., 2017). This is different in the case of Program of Activities (PoA) which allow the bundling of many small activities. In this category, which became operational after 2010, IBC activities represent a significant share. This is surprising given that the prices for CDM credits fell from 11 euros in 2011 to 0.3 euros in 2013, but can be explained by the interest of large corporations in voluntary offsets, and the willingness of several European sovereigns and the World Bank to purchase such credits at a significant premium.

In a similar tendency, in the voluntary market, carbon credits from biomass cookstove projects accounted for almost 10 % of the total transaction value between 2007-2014 (Hamrick & Gallant, 2017; Hamrick & Goldstein, 2016). Later, during 2015 and 2016, even in the depressed carbon markets, cookstove distribution remained one of the top transaction types (Hamrick & Gallant, 2017). The comparably high prices reflect the fact that IBCs are a very attractive choice for buyers of emission reduction certificates on voluntary markets. Cookstove projects are fashionable among buyers, even in low phases of the carbon market. They are straightforward to understand, easy to communicate, they target the poorest and the technology they promote

[70] While the CDM is a compliance scheme that requires national approval from the project participants and involves a registration and verification process run by the UNFCCC, in the voluntary carbon market, emission reductions are calculated and certified in accordance with several industry-created standards such as The Gold Standard, the American Carbon Registry, and the Verified Carbon Standard (VCS).

is appropriate (as they aim at improving energy efficiency and do not promote industrial gases or similar fuels).

In financing cookstove projects, carbon credits play a central role. In 2013 for example, 36 % (i.e., the largest proportion) of the financial ressources for cookstove projects came from carbon finance, according to the Clean Cooking Alliance (UNFCCC, 2014).[71]

Overall, we can summarize the funding for clean cooking interventions as follows. First, the projects in the sector are competing for very scarce overall resources and, second, carbon markets and climate finance are relevant drivers of technology choices in project planning because they play an important role in project financing. The fact that these instruments are built around the primary goal of emission reduction increases the benefit of IBCs from a donor perspective.

This situation may partly explain the popularity of IBC projects. Yet one may still expect to observe a significantly higher and growing number of LPG projects that receive funding through emission reduction credits in view of its overall benefits as a replacement of traditional biomass stoves in certain settings. The reason for this is that major climate financing mechanisms also pursue development objectives. Notably the CDM, being one of the most important mechanisms in the recent past, has two main goals. One, to promote sustainable development in developing countries and two, to support industrialized countries in achieving their reduction targets for greenhouse gas emissions. Switching from traditional cooking with partly non-sustainably harvested biomass, charcoal or coal to LPG contributes significantly to both goals as it generates emission reductions as well as substantial co-benefits, especially regarding public health and gender equality (even though these are positive side effects that would not affect whether the project passes the assessment of climate change mitigation additionality).

Against this background, the question why there are not more LPG projects financed by carbon credits is adressed in the following section, by examining under which circumstances emission reductions resulting from a switch from non-renewable biomass to LPG can be used to obtain emission reduction credits.

It is worth noting that the future of the market-based instruments in the UNFCCC framework is uncertain. This year (2020), the Paris Agreement was supposed to fully replace the Kyoto Protocol. Both the CDM and the Joint implementation mechanism under the Kyoto Protocol are hence to be replaced by Article 6 of the Paris Convention, which lays the foundation for a new generation of market mechanisms. These are designed to provide countries with cost-effective solutions for achieving their reduction targets. However, the details of Article 6 have not yet been agreed and the future of registered CDM projects is still under negotiation. Against this background, the discussion of the design of currently applicable instruments is mainly relevant for an understanding of developments in the recent past.

[71] The more recent SEforALL tracking only includes data from a few publicly funded projects when it comes to carbon finance and therefore does not allow drawing conclusions on the relevance of carbon finance for clean cooking projects.

Carbon finance for IBC and LPG project funding: Accounting issues

For an organization (a project developer) to be able to measure and certify the emission reductions of a project, it must adhere to the calculations and procedures prescribed by an applicable methodology for quantifying and monitoring greenhouse gas emissions. The leading carbon market certification schemes providing such methodologies are the following: First, the CDM, which provides Certified Emission Reductions (CER), a standardized emission offset instrument for compliance (Kyoto) markets. Second, the Gold Standard, providing methodologies for carbon credit labels with high quality in compliance markets as well as voluntary markets.

In the following, I examine the methodologies that form the basis of these two standards regarding the potential barriers and opportunities they provide to fund LPG projects as compared to IBC projects. While these methodologies differ in many respects, such as in terms of applicability criteria or baseline assessment (see The Gold Standard, 2016 for an overview), I focus on key elements that are relevant in the context mentioned above.

In the compliance market, the main methodology available for small-scale projects that relate to households and use a stove technology, which leads to emissions savings from the reduction or replacement of non-renewable biomass for heating and cooking purposes, is AMS II.G. (Lee et al., 2014: 55).[72] It applies when a cookstove with improved efficiency is introduced to lower the consumption of non-renewable biomass (NRB) and allows biomass stoves using firewood, but also charcoal and biomass fuel mixes (UNFCCC, 2017b: AMS-II.G.). Fuel switch projects, which involve moving from NRB to fossil fuels like LPG or coal, are not eligible for carbon credits under the AMS-II.G. methodology (UNFCCC, 2017a). Interestingly, UNFCCC documentation suggests that there have been internal discussions about developing a new methodology that allows switching from NRB to LPG[73], however apparently no concrete actions have resulted from these discussions.

The Gold Standard Foundation has developed its own methodology for projects that reduce or displace GHG emissions caused by thermal energy consumption through households or non-domestic facilities. It is called the 'Technologies and Practices to Displace Decentralized Thermal Energy Consumption' (TPDDTEC) methodology (The Gold Standard, 2015).[74] The TPDDTEC methodology can be used in the voluntary market only and allows for a wide range of project types. A shift from NRB to LPG is eligible for carbon credits. However, the criteria used to quantify reductions of climate-warming pollutants from replacing NRB by LPG are set

[72] These methodologies can be used for projects applying for CDM and/or Gold Standard certification for carbon finance. A further available methodology, AMS I.E., applies only to cases in which a renewable technology like solar or biogas replaces the uses of non-renewable biomass UNFCCC (2017b): AMS-I.E. This methodology (for which a switch to LPG is obviously not eligible) is only employed by few projects and will not be further discussed here.

[73] In a concept note to the Executive Board of the CDM in August 2017, a mandated Small-Scale Working Group analyzed the potential inclusion of measures for shifting from non-renewable biomass (NRB) to low-carbon-intensive fossil fuels such as liquefied petroleum gas (LPG) in AMS-I.E and AMS-II.G. UNFCCC (2017a). In recognition of the evidence on the climate impact of LPG as compared to a range of alternative stove/fuel combinations Grieshop, Marshall & Kandlikar (2011); Cashman et al. (2016); Bruce, Aunan & Rehfuess (2017), the working group recommends developing a new methodology which allows switching from NRB to LPG.

[74] Furthermore, there is also the so-called "Simplified methodology for efficient cookstoves" or under the Gold Standard, however it applies only to projects involving firewood cookstoves or projects switching from non-renewable to renewable firewood (The Gold Standard 2015) and is hence not further discussed.

in a way that leads to a substantial underestimation of emission reductions for the following two reasons.

First, the emission factor of NRB that is replaced was underestimated before 2015 and to some extent continues to be undervalued: As described above, there is no perfect combustion of biomass or charcoal in traditional stoves, that is, not all carbon in the biomass will be converted to CO_2, resulting in high emissions of products of incomplete combustions. For the calculation of baseline emissions, until 2015 the Gold Standard protocol accounted only for the so-called 'Kyoto Gases' (CO_2 from NRB and methane) and nitrous oxide by including a fixed emission factor for these pollutants. Hence, during the major part of the period during which carbon offsetting was possible, further climate forcing pollutants such as other non-methane hydrocarbons or black carbon were excluded.

As discussed in 4.1.1, residential cooking and heating is the largest contributor to black carbon emissions (Aamaas et al., 2018). Including black carbon in the calculations hence reflects climate-relevant stove emissions better[75] – let alone the co-benefits of reduced air pollution – and leads to substantial increases in the number of credits calculated (Freeman & Zerriffi, 2014). This applies for improved and clean cooking solutions in general, but particularly in the case of the very efficient combustion of LPG.

In 2015, the Gold Standard published a methodology to quantify and calculate emission reductions from black carbon and other co-emitted species such as organic carbon, CO and non-methane volatile organic carbons and sulfates. The methodology is, among others, applicable for project activities that introduce efficient cookstove technologies. However, LPG projects only benefit from this change to a very limited degree due to the following second constraint. Generally, one can distinguish between emission reductions from improved combustion efficiency and reductions from a lower carbon content of the fuel. Project activities that involve fossil fuel switching are only eligible for emission reductions related to end use energy efficiency improvements (The Gold Standard, 2016: 9). The emission reductions related to the difference in the carbon content between a non-renewable fuel and a less carbon-intensive non-renewable fuel used for substitution are not eligible, however.[76] The LPG projects in Burkina Faso and Darfur, for instance, promote the use of LPG stoves to displace traditional firewood and charcoal stoves. LPG does not only have a substantially higher thermal efficiency than firewood or charcoal, it is also less carbon-intensive than both fuels. To meet the eligibility criteria, only the emission reduction associated to energy efficiency gains are accounted for in these projects (e.g., Carbon Clear, 2013).

To summarize so far, the previous ignorance of products of incomplete combustion under the Gold Standard protocol has led to an absolute underestimation of offsets that can theoretically be achieved by displacing or reducing solid biomass use through IBCs and LPG. In addition, the change in 2015 caused a bias in the carbon market in the sense that while (in the voluntary carbon market) it partly corrected for the underestimation of IBC offsets, it did so to

[75] See 4.1.1 for the scientific debate on the climate effect of black carbon.

[76] The reasons behind the Gold Standard's approach to this are discussed in more detail in Chapter 6.3.4 ("The role of carbon markets").

a far lesser extent for LPG, since in the case of a fuel switch to a fossil fuel, the comparatively lower emission factor of LPG cannot be accounted for. Consequently, at given upfront and refilling costs for cooking with LPG, the funding generated from carbon credits that could be used to partially cover these costs is much lower than under a methodology that applies the same rules to IBCs and LPG.

In addition to these barriers for the accreditation of LPG project methodologies, there are further issues associated with carbon offsetting through IBC programs. In particular, a number of studies have shown that there is a high risk that these interventions fail to deliver the expected emission reductions. First, fuel savings are lower in real-life conditions due to technology performance in the field and fuel stacking (Aung et al., 2016). Hence, lower emission reductions of IBCs under real-life conditions lead to a further disadvantage for LPG, as the performance of LPG stoves is robust across conditions (Shen et al., 2018). Second, about 80 % of the wood fuel projects implemented under the carbon-offsetting mechanisms likely overestimate the mitigation potential of their activities since they apply excessively negative assumptions about the share of sustainably harvested wood fuel: Bailis et al. (2017) estimate that actual emission reductions are between 41 and 59 % lower than expected. However, these assumptions apply to both IBC and LPG projects and hence do not lead to a disadvantage of LPG projects as compared to IBC projects.

To conclude this section on climate-related instruments, it can be said that the way carbon-offsetting mechanisms for cleaner cooking technologies are currently designed incentivizes the use of these mechanisms to fund improved biomass cookstoves, while for LPG, important barriers continue to exist. These unequal financing possibilities through the carbon markets could play a relevant role in explaining why, unlike IBC projects, hardly any LPG projects are implemented (by non-governmental organizations and others) today. Which factors are underlying the current selection and design of methodologies, and whether the limited financing possibilities through carbon finance are actually relevant for LPG projects will be further discussed in 6.3.4 using evidence from the survey and personal interviews.

Beforehand, in a synthesis, the following section provides an overview of actor groups in the sector with their respective mandates and combines it with findings from the previous sections to explain priorities in the sector. The focus of the synthesis is on (bilateral) donors, as they dominate the sector through their resource allocation and could in principle promote both IBCs and LPG. The self-collected data presented thereafter will provide information on whether these priorities can actually be observed in reality.

6.3.3 Actors, mandates and interests

As we have already seen from the historical outline in Chapter 5, there is a large number of organizations engaged in the clean cooking sector. Few of them are dedicated exclusively to the promotion of alternative cooking technologies, e.g., through analytical work, coordination, advocacy, and other sector development activities. In addition, a large number of organizations address the issue from their own perspective. They can be roughly grouped into the three (overlapping) policy domains of health, climate/environment and development/poverty reduction.

Table 3 gives an overview of the groups of actors and the options that correspond to their interests according to the political-economic analysis. To begin with, there are organizations which are mainly interested in reducing (household) air pollution, since their mandate is to promote global health and/or reduce the climate- and health risks from short-lived air pollutants. Key players in this group are the WHO, regional health organizations or organizations and NGOs fighting air pollution and short-lived climate pollutants, on the international level namely the Climate and Clean Air Coalition (CCAC). They will typically favour LPG over IBCs (see Table 3). For many years, these organizations have explicitly supported a stronger focus on the cleanest fuels and stoves, for instance through the publication of emission guidelines (WHO, 2016), high-level advocacy, standards and testing protocols, and financial support to the technologies and fuels that reduce short-lived climate pollutants (CCAC, 2019).

Then there are organizations with a climate- or environmental focus, namely international environmental NGOs and international environmental organizations. Given that LPG is a fossil fuel, a strategy that excludes its promotion and instead prioritizes IBCs is rational. In accomplished interventions, environmental organizations appear to have focused on efficient stoves, emphasising their positive effects on the environment, especially their reduced wood consumption (e.g., WWF, 2014).

Table 3 Organization types and clean cooking preferences

Mandate	Main organizations	Priority consistent with interests
Reducing air pollution and its risks for health (and climate)	Health IOs (WHO), CCAC	Clean fuels including LPG
Climate- / Environment protection	Environmental NGOs, Environmental IOs	Biomass and renewable energy technologies
Development	Development agencies, Development NGOs, Development banks	Cleaner stoves and fuels, but not LPG
Sector promotion and coordination	SEforALL, clean cooking organizations	Clean stoves and fuels including LPG

Organizations with a general development mandate or interest include international and national development NGOs and foundations, national development agencies and development banks. These organizations could in principle promote both IBCs and LPG. From a poverty reduction perspective, the integrated possibilities of advancing sustainable development by promoting clean cooking alternatives would need to be considered, including their climate- and health benefits, and beyond that, the promotion of the local economy, gender equality and other social benefits. Aid organizations do not deploy their resources simply based on purely technical criteria. Their decisions are guided by, amongst other factors, the preferences of their donors, political norms and economic incentives that are in turn shaped by the institutions in the sector. In this context, the analysis in this chapter suggests the following:

One the one hand, there is some pressure on donors to comply with the new performance standards for cleaner cooking technologies by increasingly supporting the cleanest fuels and technologies. Yet, these standards are primarily of an informative nature and there is no obligation to choose the best-performing devices in terms of reducing health-damaging emissions. Financial incentives have a stronger influence. Bilateral donors have restricted means; hence, it is rational to provide support to residential energy-access projects through climate finance, carbon finance or other budget lines tied to climate goals or the promotion of renewables. This allows using restricted public funds in the most cost-effective way since they contribute to commitments and targets in the areas of development and climate action at the same time. Climate finance and carbon finance instruments are built around the primary goal of climate change mitigation. Therefore, it is very attractive for bilateral donors to allocate their resources to projects promoting technologies based on renewable energy sources, while supporting LPG would require higher total expenses, as no other budget line – such as for climate finance or the promotion of renewables – can be used to promote it. Ministry-involvement, and the aim for a promotion strategy that is consistent with national and international political norms for climate action and the public interest (including the support of "charismatic carbon projects" (Lehmann, 2019)), e.g., through the promotion of renewables and the elimination of fossil fuel subsidies, further underpin the rationale for this strategy. Therefore, the political arguments against promoting LPG, a fossil fuel, in development interventions are strong.

Finally, there are organizations that are specifically devoted to the development of the clean cooking sector such as the international and national clean cooking alliances, and the Global LPG Partnership. When allocating their resources, they need to pay attention to the international norms in the sector, which put an emphasis on high-performing appliances concerning pollution reduction. At the same time, these broadly based organizations with coordinative functions are highly dependent on their main donors and the preferences of the members in their governing boards.

Overall, this part of the empirical analysis based on literature and reports suggests that while there is a distinct trend in the sector towards high-performance appliances, it is politically and economically not rational for the major donors to choose a strategy that prioritizes LPG. Different institutions structure the norms and incentives influencing donor priorities, those related to international climate policy being the most powerful in this respect. However, the orientations and, relatedly, the different target audiences of the different organizations, should lead to some heterogeneity in the portfolio of projects they promote.

These findings concerning the role of dominant norms and incentive structures in the sector need to be validated by triangulating the evidence with more information from alternative data sources. In addition, complementary information is required in order to understand which ideational and other factors are shaping donors priorities. For instance, an organization may be opposed to LPG promotion because its decision makers assess the scientific evidence on the impacts of IBCs and LPG differently than others, because LPG is a fossil fuel or simply for practical reasons. As outlined in the analytical part, I assume that representatives of key organizations in the sector draw on these assumptions, values and ideologies to form their preferences and based on these preferences, allocate their resources in a way that best correspondes to their interests, within the framework conditions of the sector.

The information provided by actors in the sector further offers anecdotal insights into how the allocation of multilateral donors and financing instruments is shaped by these institutions' governance structures and the power of bilateral donors, and how donor values shape institutional settings (such as the design of financing instruments) over the long term.

Finally, more evidence is needed on the actual current and future resource allocation to LPG and IBC interventions in the sector in order to test whether the ‘rational’ priorities outlined here are actually observed.

The second part of this empirical analysis therefore provides evidence to address these issues using self-collected data, particularly on key actors’ actual and future resource allocation and on their assessment of cooking alternatives.

6.3.4 Information on attitudes and the actual allocation of resources

I collected information on the role of LPG and attitudes towards its promotion through an online survey among experts representing key organizations engaged in the field. In determining the sample for the online survey, I sought to include the most important bilateral and multilateral donors and to ensure the highest possible representativeness for the sector. Specifically, I aimed to ensure that both the diverse perspectives and interests associated with the topic and the different activities, such as project implementation, financing or advocacy, are each represented by several organizations.

I received responses from 48 experts, but excluded those from industry and research institutions, eventually resulting in a sample of 44 responses from 39 organizations.[77] They essentially mirror the above-mentioned activities in the sector and generally represent well the diversity of interests and policy areas associated with the issue of clean cooking. Excluding responses from the production sector and from researchers (who are primarily public health

[77] To gain a more in-depth understanding of the sector, I initially contacted a number of representatives from research institutes and the industry (LPG industry and IBC producers) in addition to the other types of organizations in the area (see sample frame in Appendix D). However, no answer from an IBC producer could be obtained. To avoid any bias and because industry and research do not directly influence the design of programmes, I finally chose not to include the answers from these areas in the statistical analysis of the online survey.

scholars) means that only a few of the strongest proponents of LPG are represented in this survey. However, I do not consider this problematic, as in this empirical part of the study, we are mainly interested in organizations that (unlike researchers and the industry) have a stake in the actual allocation of resources for stove programs. Appendix D provides all methodological information, including details on the sample frame, the interviewees and on the procedure used to conduct the survey. It also displays the questionnaire. The survey questions were organized around the following key topics:

(1) The assessment of empirical evidence on health- and climate-impacts from using LPG as compared to improved biomass stoves
(2) Attitudes towards different factors that may speak in support of or against increased LPG promotion.
(3) The role of LPG as part of the clean cooking activities of the organization in the past, today and in the future
(4) The political viability of a stronger focus on LPG, including donors' preferences
(5) Views on increased efforts to promote LPG

In addition, I conducted eight personal interviews with experts from development banks, non-governmental organizations, donor countries and the carbon market to enable a deeper understanding of selected processes and relationships, to put statements from the online survey into perspective and to clarify open questions. Detailed documentation of these interviews is provided in Table A 11 (Appendix D).

In the following, I analyze the responses provided in the online survey, and clarify and contextualize them with the help of the personal interviews. I begin by presenting my findings on the perceptions and attitudes of the actors (key topics 1 and 2), on the programmatic and ideological level. The focus lies on the aspects I identified as relevant with respect to preferences for certain interventions in the theoretical part. Most notably, how do experts assess the relative benefits of the different technologies regarding sustainable development goals such as better health, climate protection or social equity? In their view, is it consistent with the concept of sustainable development to promote LPG? Which other barriers for LPG promotion do they see?

I then report the survey's results on the actual resource allocation of key organisations today and in the near future, and on what respondents think of strengthening support for LPG overall – including from a political perspective (key topics 3 to 5). In doing so, the objective is to obtain an accurate account of how the sector and the general attitudes amongst professionals who operate in it are currently evolving.

Ideas: Values and assumptions regarding the promotion of cleaner cooking alternatives

What are the values and assumptions on which representatives of key organizations in the sector base their policy preferences? How do they assess the findings from scientific studies in the field? The following analysis of survey responses addresses these questions and hereby takes reference to key arguments in the debate on the viability of promoting LPG.

Climate impacts of LPG promotion – transition fuel or carbon lock-in

LPG is a fossil fuel. The common narrative of LPG proponents is therefore that the ongoing focus on biomass stoves by some key actors is mainly driven by their desire to combat climate change by promoting renewables (Goldemberg et al., 2018). To determine to what extent this narrative conforms to actual views the survey inquired how professionals in the clean cooking sector assess the use of LPG as cooking fuel from a climate perspective.

When asked to judge the scientific knowledge regarding the climate benefits of LPG as a replacement for traditional biomass cooking, respondents assessed LPG as performing somewhat better than or similar as IBCs on average.[78] The assessement varies considerably, but there are no clear differences between the interest groups, i.e., between the organization types oriented towards environment, development and health respectively (see Figure A 1 in Appendix C). Due to the small number of respondents, the disaggregated results need to be treated with caution, though. Interestingly, development organisations (bilateral donors, development NGOs and development banks), tends to see LPG as marginally superior. The majority of respondents' assessment is hence consistent with the current scientific understanding of the climate-related effects of using LPG as cooking fuel as compared to traditional solid biomass use.[79]

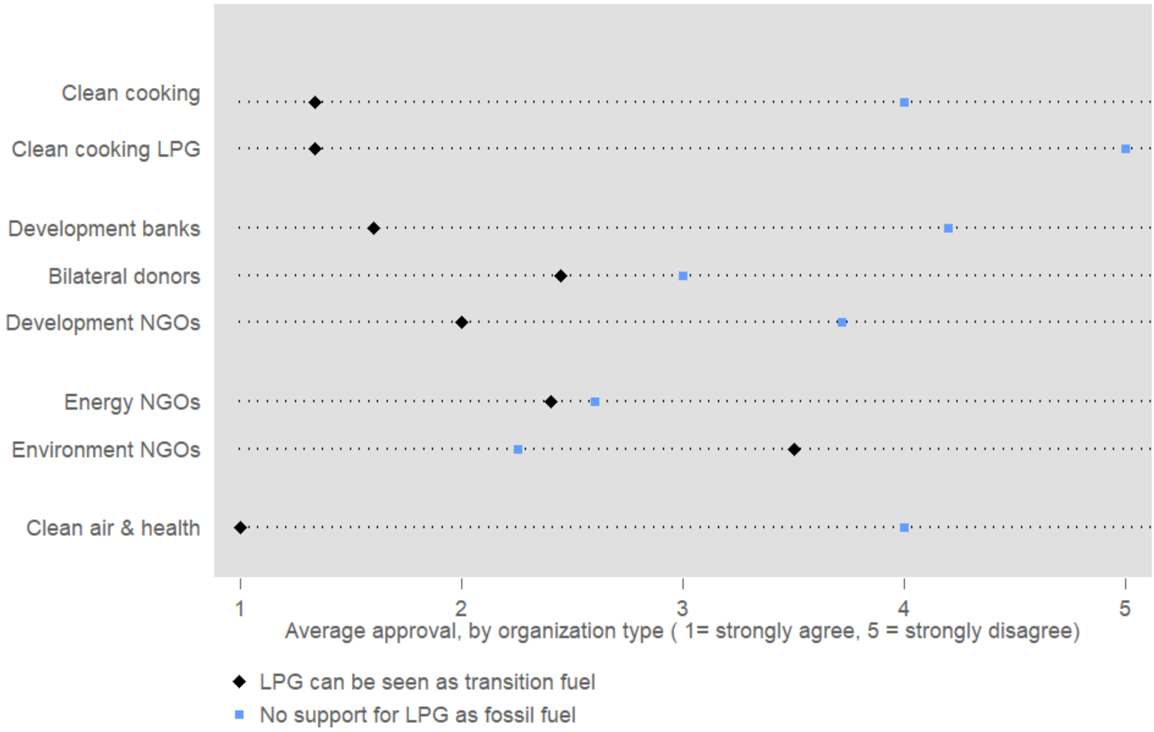
Note that the survey question and the scientific evidence on the issue refer primarily to the combustion process or the product life cycle of the fuels to be compared. Against this however, an increased LPG production could deteriorate the *long-term* prospects to mitigate climate change, as it affects global energy markets, such as the conditions for fossil fuel extraction or global energy prices. The survey results and interviews indicate that regarding this broader perspective, opinions about promoting LPG as household fuel vary widely between actors from different interest groups.

Figure 6 shows to what extent the respondents agree with the statements that (I) LPG can be seen as a transitional solution for clean fuel until electricity and renewable fuels are accessible everywhere, or whether (II) LPG should not be supported because it is a fossil fuel.

[78] Weighted mean (to correct for multiple responses from individual organizations) = 2.55 on a scale from 1 to 5 (1=much better, 5= much worse). For the comparison, respondents were asked to refer to the real-life effectiveness of these options as a replacement for traditional biomass cookstoves and the type of improved solid fuel stove most commonly promoted by their organization.

[79] As summarized in 4.1.1, the evidence available today suggests that when short-lived climate pollutants (SLCPs) are considered, the use of biomass fuels in terms of climate impact is unfavorable compared to LPG, which burns much more completely. When compared to improved biomass stoves, the evidence available so far implies that LPG performs similarly to efficient types of improved biomass stoves for net CO_2 emissions in contexts in which the wood fuel is harvested partially renewably, and better than IBCs for black carbon and other SLCP.

Figure 6 Views on LPG as a transition fuel and on rejecting its use as a fossil fuel



Note: 'Clean cooking' stands for clean cooking platform initiatives such as clean cooking alliances and 'Clean cooking LPG' for responses from the Global LPG partnership. 'NGO energy' stands for NGOs, think-thanks or social businesses that are specialized on energy and sustainable development (with an energy focus).

The markers show average approval rates by organization types, grouped according to their mandates. On the one hand, many experts see LPG as a viable transitional fuel until electricity or scalable solutions based on renewables are available everywhere (74 % agree somewhat or strongly).[80] This applies particularly to respondents from organizations with an interest in health, clean cooking promotion, but also to representatives of development banks, as illustrated in Figure 6. Several of them point to different environmental problems caused by LPG during personal interviews and consequently emphasize the role of LPG as a bridging technology that is to be replaced by electricity in the long term. At the same time, they stress that, now, LPG is the only scalable, clean fuel in many contexts. They also suggest that the additional climate-warming emissions from households switching to LPG use are very small (if any) in the global context and do not carry much weight compared to the enormous benefits for human health (interviews P2, P4, P6).

On the other hand, there is a strong minority (33 %), particularly in environment and climate organizations, who do not accept the promotion of fossil fuels for household energy solutions and therefore believe that LPG should not be promoted (see Figure 6).[81] In this context,

[80] Weighted mean across all respondents = 2.1 on a scale from 1 to 5 (1= strongly agree, 5= strongly disagree).

[81] Average approval across all respondents (weighted mean) to the statement "LPG should not be promoted because it is a fossil fuel" was 3.38 on a scale from 1 to 5 (1 = strongly agree, 5 = strongly disagree).

a number of arguments is put forward that refer to the relevance of the long-term perspective, in particular the fear of carbon lock-in.

A representative from a social business promoting solid biomass stoves emphasized his concerns about increased gas consumption by a large number of people in a personal interview:

> How about the social and environmental issues related to extraction? What about this discourse saying natural gas is just, how do they call it, like the secondary products of oil and so it is like free. […] And most importantly, what is the trajectory? What do we believe is meant to happen for the planet if we are having 3 billion people now using gas? What is the trajectory for a country and where does a lock-in situation happen? Is it a good transition fuel or will we have lock-in situations? (Interview P5)

In line with this, a project developer for cookstove interventions financed through emission reductions argued that the demand for LPG should not increase but decrease, as a small reduction in prices could make the worst kind of fossil fuel extraction – fracking – unprofitable (interview P9). From this perspective, all interventions that lead to increased consumption of fossil fuels need to be avoided, regardless of the fact that fuels differ in their impact on the global climate.

In this context, those who do approve LPG as a transitional solution tend to see themselves as pragmatists. With respect to other donor institutions that do not promote LPG, some believe that government officials sometimes take an ideological or idealistic approach to development rather than a pragmatic one and take decisions based on "gut feelings" or "controversial feelings triggered by LPG" without much further thought (interviews P3, P4, P6).

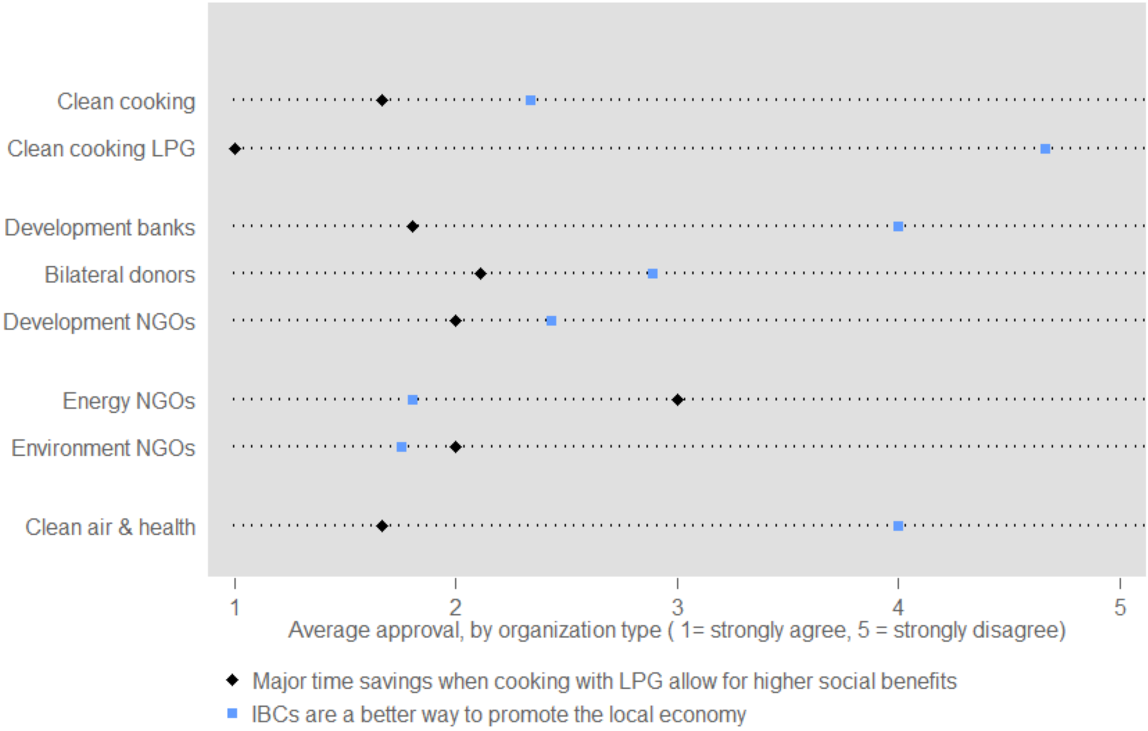
Some respondents did not respond to the questions related to the assessment of scientific evidence on the health- and climate benefits of LPG respectively, and some respondents (18 % for health, 23 % for climate) stated that they did not know. There is a strong correlation between the 'don't know' answers to both questions. Moreover, the acceptance of stronger efforts for LPG promotion is significantly lower among survey participants who state that they do not know how LPG compares to IBCs, whereby this relationship applies to both the questions on health and on climate benefits.[82]

Social benefits and local economy

In addition to climate protection, social benefits and the stimulation of the local economy – e.g., through the local production and maintenance of stoves and timesaving in wood collection – are common arguments used to motivate clean cooking interventions. Figure 7 summarizes how respondents compare LPG and IBCs with respect to these factors.

[82] Respondents were asked whether they agree that efforts to promote the adoption and use of LPG should be increased (on a scale from 1 to 5, 1=strongly agree, 5=strongly disagree). As an example, the average score among respondents stating that they don't know about the climate benefits of using LPG vs. IBC was 3.44, and 2.17 among the others (p =0.01 in two-sided t-test).

Figure 7 Views on LPG vs. IBCs concerning social benefits and the local economy



Note: Average approval (weighted mean) for statement on social benefits = 2.01. Average approval (weighted mean) for statement on local economy = 2.78. 'Clean cooking' stands for clean cooking platform initiatives such as clean cooking alliances and 'Clean cooking LPG' for responses from the Global LPG partnership. 'NGO energy' stands for NGOs, think-thanks or social businesses that are specialized on energy and sustainable development (with an energy focus).

The views are most apparent in the area of social impacts. A majority of the experts (70 %) believe that due to the large timesaving potential, cooking with LPG allows for higher social benefits than IBCs, in particular for women. Only energy-related NGOs, which are on average indifferent, represent an exception to the consensus.

Regarding the local economy, views vary widely, there being much weaker general agreement on this point than on timesaving potential. Organizations with an environmental interest tend to believe that IBCs are better for the local economy, while this view receives somewhat less support among development NGOs. Bilateral donors and clean-cooking initiatives do not have strong views on this aspect, while development banks, health-focused (including academic) organizations and LPG organizations disagree.

The experts were also asked for their assessment as to which technology would probably best suit the preferences of the households concerned. Somewhat surprisingly, the largest fraction of respondents (48 %) was not sure whether LPG corresponds better to household preferences or not, whereas some agree, and some (slightly fewer) disagree. These results may be an indication that some program implementers and donors are not very well informed about the kind of appliances and fuels energy-poor households prefer using when given the opportunity to choose. Recent field research from India, for instance, suggests that households across all communities choose the cleanest cooking solutions (LPG and induction) if given a choice (Menghwani et al., 2019).

The arguments discussed so far already relate to the various aspects of sustainable development. Yet what about the concept of sustainable development itself – is promoting LPG consistent with the prevailing understanding of sustainable development in the sector?

Compatibility with sustainable development

Two thirds of surveyed experts are of the opinion that promoting LPG is consistent with the Sustainable Development Goals, while only 18 % disagree. The strongest proponents of SDG-conformability are those with a mandate to promote health or the (non-profit) promotion of LPG, but also organizations that promote clean cooking in general and development banks. Yet, even though only few respondents feel that promoting LPG does not conform to the idea of the SDGs, more than one third believes that IBCs are a better way to put the integrative idea of sustainable development into practice. This view is strongest among representatives of environmental, energy and climate NGOs. Across all respondents, opinions vary widely, though, as 35 % disagree. This number is driven by responses from health-focused organizations, NGO representatives promoting LPG and development banks (see Figure A 2 in Appendix C).

Health benefits and poverty

The respondents were also asked to assess the scientific knowledge regarding the health benefits of LPG as compared to improved solid fuel stoves as a replacement for traditional biomass cooking. On average, respondents consider LPG clearly superior to improved stoves in terms of health benefits, as 84 % believe that the health benefits from LPG are somewhat or much better than IBCs, but only 3 % think it is somewhat worse.[83] Figure A 1 in Appendix C shows differences across interest groups. A very similar further question supports the general findings regarding the experts' views on health impacts: 70 % expressed agreement that improved solid biomass stoves do not yield sufficient benefits for health, while 18 % disagreed. Respondents who disapprove of this statement mainly belong to general clean cooking organizations and environmental NGOs.

Regarding the assessments of health benefits of different cooking technologies, section 6.3.1 described how standards to evaluate the performance of cooking devices and fuels have evolved over time and are now formalized at the highest international level. Insights from the personal interviews lend support to the expectation that these standards have become increasingly important guidelines for stakeholders and that they tend to give greater weight to the *cleanest* technologies such as electricity, LPG or biogas.

This is reflected on the one hand in the fact that important actors in the sector, such as the World Bank or EnDev, have adopted result-based financing approaches: Depending on the clean cooking performance, financial incentives are provided for the private sector to deliver

[83] Average assessment of LPG as compared to IBCs was 1.7 (weighted mean) on a scale from 1 to 5 (1= LPG is much better, 5 = IBCs are much better), see Figure A 1 in Appendix C for details.

clean cooking services (interview P1). On the other hand, proponents of IBCs criticize the design of the standards with regard to health-related emission reductions and advocate adjustments in favour of IBCs, as the following examples illustrate.

A representative from a social business promoting IBCs argues that assessments of health benefits of different cooking technologies are based on assumptions and emission standards that often do not correspond to the use of the appliances in reality and are therefore distorted. In particular, he argued that fuel stacking with very irregular use of LPG will remain a reality for the poorest and hence, in this more complex comparison system, IBCs may reduce emissions more effectively than a combination of traditional cooking and LPG (interview P5).[84] In this context, proponents of IBCs tend to criticize the increasing focus on clean fuels, whereby they would also question the word 'clean' itself. A prominent expression of this criticism was the 'Wexford declaration' in May 2019, in which a large number of supporters of more efficient biomass cookers called for sector-wide discussion and a new, 'technology-neutral' definition of the sustainable energy indicators (International Pathways to Clean Cooking conference, 2019).

These observations suggest that many IBC proponents see formalized standards to assess the performance of cooking devices as a threat to the proliferation of IBCs. Although health concerns appear to be an increasingly important driver of current efforts to promote clean cooking, even those experts who advocate ambitious performance standards point out that the situation of affected households needs to be assessed holistically. In particular, the affordability of energy services needs to be taken into account. In this context, 62 % of the professionals believe that when relying on LPG, households become subject to the interests of international corporations and to highly volatile energy prices. These concerns are most strongly voiced by development and environmental NGOs (see Figure A 3 in Appendix C).

A high-level staff member of the World Bank's clean cooking program also emphasizes that higher LPG consumption may undermine household energy security:

> […] it's not that health is the only objective of any energy policy. It is a very important dimension […] from a household perspective, […] increasing the knowledge that smoke is bad for health will help them [the members of the household] to make a better decision. That does not mean that they need to spend more than 10 % of their income on fuel. Because you are pushing them into energy poverty. The poorer the household, the more sensitive to the costs or the price. Because if you have limited budget how do you prioritize […] So it always has to be a balanced approach. (Interview P1, amendments in parentheses are by the author).

Barriers to scale-up

The issue of affordability as an important argument in the discussion has already been touched upon above. Such practical challenges are regularly used as arguments in the debate on alternative clean cooking technologies and were therefore addressed in the survey and personal

[84] Further critiques refer, for instance, to the tests for emission reductions which are based on one-pot-stoves while households often use two-pot stoves.

interviews. In the analysis of the personal interviews, the focus is on the contributions of the relevant national and international actors and their interaction, and especially on financing aspects.[85]

Almost two thirds of the survey respondents believe that the barriers to scale up LPG, especially regarding affordability and availability, may be too high. Representatives from NGOs and some bilateral donors are particularly prone to this view. Among development banks, clean-cooking initiatives, and health-focused organizations, the barriers are seen as less unsurmountable and professionals promoting LPG in a non-profit organization strongly disagree (see Figure A 3 in Appendix C).

Nevertheless, there is general agreement that LPG often remains unaffordable and inaccessible for many households, despite promotion efforts. Experts from development banks and GLPG emphasize the need to further accompany measures (interviews P1, P2, P3, P6). An IDB expert for instance points out that

> […] one problem is that it is easier in general for development institutions to give away a device such as a stove, but with LPG you need to provide support to access the fuel, namely you need to accompany a project during several years in order to ensure that there is a delivery model that enables people to continue using that. And this is more complex, of course. (Interview P2).

As the expert points out, implementing such measures is complex and associated with problems. In particular, while LPG subsidies can address affordability issues, universal price subsidies are disapproved, given their well-known environmental, social and economic effects and the heavy burden they put on government finances (interviews P1, P3). Targeted subsidies for the poorest, while seen as a theoretically viable measure, require technical capacities that many countries do not have (interviews P1, P3).

It is worth noting here that actors in development assistance generally have difficulty with payments made on a permanent basis because they are under constant pressure to deliver sustainable results in the sense of one-time payments providing lasting benefits. In other words, donors usually do not engage in permanent payments, which is why, in the case of LPG, they may finance for instance information campaigns or the development of performance standards for cookstoves, but no permanent subsidies. This presents another barrier to scale up LPG.

Governments, meanwhile, can use subsidies to improve access to LPG. Setting up an appropriate infrastructure for the import and distribution of LPG is primarily up to the industry and large investors though (interviews P3, P6). However, under the prevailing market conditions, the industry has no interest in investing to extend its offer to remote areas (interviews P3, P6).

[85] Market conditions or acceptance by households will thus not be discussed in detail in the context of this work.

Additional financial support is therefore needed for individual parts of infrastructure development, possibly through financing from development banks (interview P6). Creating enabling conditions furthermore requires analytical work, which external actors like GLPGP or development banks may provide, in close collaboration with the industry and relevant ministries (interviews P2, P3, P6). However, this demands (i) a national government that is committed to the expansion program and supports it with own policies and resources, and (ii) international donors willing to fund the external support.

Hence, with respect to the barriers to widespread LPG use, several experts stress that a private market cannot be created on its own and that public support from national governments and the international development community is needed (interviews P1, P2, P3, P6, P8). When elaborating on the need for a strong policy push, experts often refer to the case of India, where the government seeks to expand access to LPG to 80 million rural poor households by essentially covering the upfront costs of the stove and cylinder and by improving the supply in remote areas.

Promoting IBCs, in contrast, primarily involves the distribution of appliances themselves, which are commonly inexpensive and hence a very cost-effective way of generating emission reduction certificates (interview P9). Consequently, IBC interventions are appealing from a donor perspective, as a public health scholar observes: "Investing in solid fuel stoves lets donors off the hook, giving a false impression that real benefits can be obtained with an appealing modest investment in locally improved technology." (Individual comment in survey response S 82).

The role of carbon markets

Given this context, to what extent could additional funding through carbon finance facilitate the promotion of widespread access to LPG? An expert for carbon markets and methodologies to quantify emission reductions clearly sees the possibilities to augment the prospects of LPG projects through carbon finance, as these revenues can make LPG more affordable for the user. At the same time, he fears that they will not be sufficient to trigger a switch from biomass to LPG. He also points to the need to set up a supply chain, which a carbon project alone will not be able to do (interview P8). Against this background, he underlines the critical role of vigorous policy measures:

> […] my sense at least from the Indian example is that the carbon [finance] in itself might not be a huge factor in moving to LPG, I think you would need a policy push, simply also because LPG is much, much more expensive […] you have to pay for LPG whereas biomass can be collected for free […]. (Interview P8, amendment in parentheses are by the author).

He sees this difficult environment both as a potential reason why there are not more projects funded through carbon finance and as a possible explanation to why the CDM methodologies were not adapted to allow for carbon-offsets from a switch from NRB to LPG, or why a new methodology has not yet been developed by users:

> I think the reason why we do not find you know, developers, or we do not find a lot of traction is simply because a vast majority of the developing world is still heavily reliant on solid biomass, or solid fuels for cooking. So, I think there probably was not even a business opportunity in that sense, you know, to go and develop an LPG-based methodology simply because it would not have widespread applicability. Indeed biomass methodologies can be applied much more widely. (Interview P8).

Emission reductions that occur when switching from NRB to LPG projects can only be certified using the Gold Standards TPDDTEC methodology and sold on the voluntary carbon market. The fact that no claims can be made based on the difference in carbon content leads to a substantial underestimation of the actual reduction of climate-active gases and pollutants (see subsection on carbon finance for details). What is the rationale behind such restrictions that are at odds with the goal of giving people access to clean fuels through the highest possible revenue from emission reductions?

According to the expert for cookstove methodologies, the carbon content cannot be claimed because the Gold Standards' policy is not to promote the use of fossil fuels, but only zero or less GHG-intensive fuels. The LPG methodology was designed to "help people move up the energy ladder", but is described as an exception from the general principle:

> Gold Standard does not promote the use of fossil fuels. However, the Gold Standard understands that there are scenarios where you would have to use fossil fuels, but as long as there is an efficiency gain in the project scenario as opposed to the baseline, and [as long as] there is also a very strong possibility of providing, say, the developing world with access to basic human needs. In those situations, you know, exceptions are made, for example with the cookstove methodology. But other than that, as a policy, you will not see large-scale methodologies […] where Gold Standard allows any kind of fossil fuel usage. (Interview P8).

Overall, the opportunities for LPG financing through the carbon markets are thus deliberately limited. Yet, insights from the interviews suggest that the negligible role of carbon finance for LPG projects is not so much attributable to the methodologies used to quantify emission reductions as to the complex realities on the ground. In other words, the discussion in this section showed that setting up the required infrastructure for large-scale LPG distribution and creating market conditions that allow low-income households to use LPG as their primary cooking fuel is a challenge that requires coordinated action, a strong push from policy and financial support from national and international actors. In light of these realities, carbon finance could make a financial contribution to LPG programmes, but there is little potential to implement interventions primarily financed by carbon finance in most developing countries concerned.

Ideologies and approaches to development

Finally, in addition to the somewhat contrasting assessments of the potential benefits of clean cooking alternatives and of the barriers in providing access to them, some respondents also felt that there were ideological differences between supporters and opponents of LPG regarding their development policy approach.

In particular, behind LPG, there is an entire industry, and scaling up requires large-scale investments (interviews P3, P6). A senior official of the KfW – one of the very few bi-or multilateral donors providing support to the Global LPG Partnership – feels that the fact that LPG requires large investments provokes `defensive' and to some extent `anti-capitalist' reactions. That is, some actors in the development policy field conclude that LPG does not fit into their development policy concept, as the following reasoning illustrates:

> Well, part of it, I'd say, is a bit 'anti-capitalist'. When you think a little bit about what needs to be done for LPG. First, you have to build a quay in the port for X millions, and then you have to buy special ships for Y millions, and build domestic pipelines. Some 'capitalists' back this. That is one part of it. The other part originates from that 'small is beautiful' school. It is not 'small' if I have to say, I need a berth where a huge ship can discharge an enormous amount of gas. Then I need dozens of heavy steel machines that can fill it. This is not local. That makes a difference. (Interview P6, translated from German).

This may also explain differences in actor positions independently of their sectoral focus on health or environmental issues. In particular, it can explain why development banks, which mainly employ economists, tend to take a different stance towards LPG than other development agencies or, in particular, NGOs, whose staff is often more heavily influenced by general anti-capitalist ideologies.

Empirical evidence on the role of LPG and related resources

The debate on cooking technologies revealed that the sector's actual development is perceived in different ways. While proponents of the cleanest technologies argue that the main donors continue to rely primarily on biomass cookers, others, such as environmental NGOs, say they are experiencing a strong trend towards promoting LPG. It is therefore worth shedding light on how much of their resources organizations actually allocate to LPG interventions and what their plans for the future are.

Reports from the SE4ALL finance tracking suggest that, overall, providers allocated most financing commitments in 2015-16 and 2017 to improved biomass cookstoves, followed by alcohol stoves, biogas digesters and advanced biomass stoves. Tracked finance to LPG amounts to \$4.6 million, as compared to \$15 million for improved and \$4 million for advanced biomass stoves. [86,87] Combined with the findings from the academic and grey literature (see Chapter 5), the report thus confirms that support to modern fuels through international development cooperation has somewhat increased in recent years, but still remained below the efforts

[86] Advanced stoves are high performing cookstoves which are very efficient and therefore have low emissions. Advanced stoves are usually gasifier stoves or forced air stoves, both working with processed or raw biomass.

[87] Imported volumes of LPG cylinders are not considered in the report's comparison.

that might be expected given their scope to reduce global health burdens from indoor air pollution.

However, shifts in development thinking and practice usually take time. Hence, program priorities could simply be slow to change, while LPG programs are in the pipeline but not (yet) implemented. Moreover, the data do not allow us to differentiate the actors in the sector who claim to be in favor of increased efforts to promote LPG from those who are indeed placing more emphasis on LPG in their resource allocation.

This section therefore provides further evidence from self-collected data to address these questions. Drawing on the standardized survey and personal interviews among representatives of key organizations in the sector, it provides an in-depth picture of the role that actors in international development cooperation assign to LPG and to what extent they invest in corresponding projects. Note that not all organizations finance or implement interventions directly, e.g., international public health organizations.

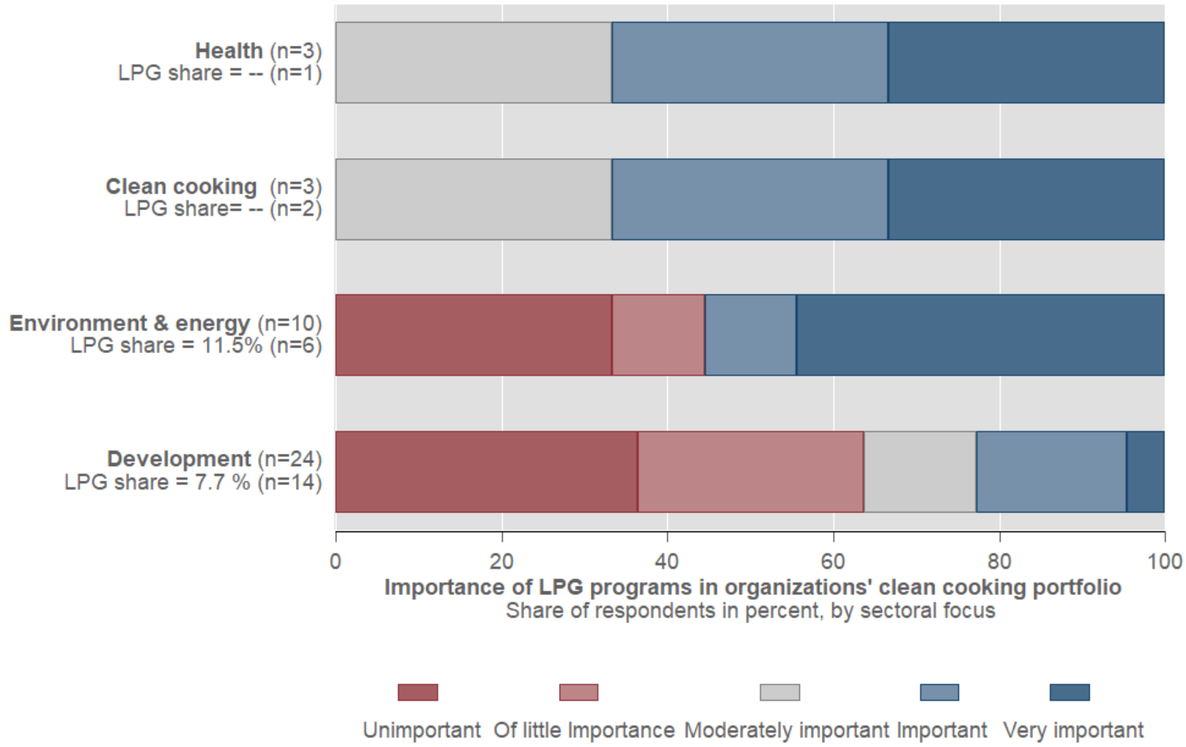
Current role

The relevance that actors assign to LPG in their clean cooking portfolios varies widely. When asked how important LPG programs are for their organization, as compared to programs promoting other fuels and technologies, almost half of the respondents state that LPG is unimportant or of little importance for their organization, while 38 % report that it is important.

Figure 8 provides an overview of the relevance that respondents attach to LPG programs in their organizations' clean cooking portfolios, grouped by the organizations' sectoral focus. Generally, the results show that, as expected, LPG is significantly more important for health-focused organisations and clean cooking initiatives (including GLPG) than for the other players. Development organizations attach the least importance to LPG, as only about one-fifth of respondents consider LPG to be important for their organization.

Yet, considering LPG as relevant does not necessarily imply that a corresponding share of resources is allocated to it, as revealed by a further survey question, that asked participants to indicate which proportion of clean cooking resources their organization spends on LPG (see mean values for 'LPG share', by sectoral focus in Figure 8). Here, not many participants reported a specific value and within the context of the survey responses as a whole, it is likely that many of the missing values would actually be zeros. Therefore, the indicated LPG shares are to be understood as upper bounds and generally need to be interpreted with caution. No average LPG shares are reported for groups with less than three responses. The results nevertheless suggest that the financial resources actually used for LPG are modest.

Figure 8 Role of LPG in clean cooking portfolios



Note: Respondents were asked to state how important LPG programs are for their organization, as compared to programs promoting other fuels and technologies. In order to avoid distortions, only one answer was included from organizations with multiple respondents. However, the aggregate result is not dependent on who is excluded, as the excluded answers to the relevant questions were either the same as those taken into account or left blank. 'Health' refers to public-health organizations as well as organizations with a focus on reducing air pollution. 'Clean cooking' in this figure includes all clean cooking initiatives including those focusing on LPG. 'Environment & energy' summarizes responses from all environmental and energy NGOs (and social businesses), whereas 'Development' refers to Development NGOs, bilateral donors and development banks.

Among the organizations that actually develop or implement clean cooking programs, some development banks, clean cooking platform initiatives (or their partners) and energy-oriented NGOs and social businesses today allocate relevant parts of their clean cooking resources to LPG (up to 20 % of clean cooking resources, more for some clean cooking initiatives). However, among bilateral donors as well as development- and environmental NGOs, the share allocated to LPG is extremely small, if indicated at all (clearly below 10 %, mostly 0 %). Many bilateral donors indicated that their country's aid to energy projects was not structured in a way that allows them to identify the role of LPG and that consequently, they were unable to quantify its importance. Most of them noted, however, that LPG is of little importance or unimportant for their organization. A notable exception is Japan, which has not directly funded any clean cooking projects so far, but is considering promoting LPG access in the future (survey response S9). These results indicate that the focus on IBCs is most pronounced among European donors.

Among the development banks, several representatives state that LPG is important to them as a means of promoting clean cooking. Yet, actual resource allocation is minimal.[88] Apart from some funding for analytical work and feasibility studies by KfW (and ESMAP), currently only the AfDB has investment projects for LPG (50 % of resources) (interviews P1, P2). The World Bank representative emphasizes that the Bank generally promotes clean cooking solutions based on performance and based on the context and that there is no single solution that fits all contexts (interview P1).

Similarly, EnDev has so far only implemented projects for biogas, wood or charcoal stoves (survey response S30, interview P4), arguably also underpinned by EU legislation supporting renewables (interviews P3, P4). Regarding the Alliance, according to its guiding principles it has always been committed to technology and fuel neutrality. In the past, the lion share of its support has focused on IBCs (Clean Cooking Alliance, 2018b). Data from 2015-17 reveal a stronger focus on ethanol, biogas and pellet/gasifier stoves, and that some capital was also raised for LPG (7 %) (Clean Cooking Alliance, 2019a: 5). The head of a social business promoting IBCs confirms such a shift within the Alliance, which he criticizes as being linked to lobbying activities by the industry: "[…] four years ago, [the Alliance] started speaking about LPG, started inviting the LPG lobby, the World LPG Association to all of their meetings" (Interview P5). [In fact, it was the non-profit GLPGP, setup by SEforALL but not the industry representatives.]

Concerning private foundations, the data available does not provide sufficient evidence on the extent to which funding is allocated to LPG scale-up promotion.[89] The GLPGP representative expressed the opinion that private foundations either don't address clean cooking at all or may do so through promoting renewables. She bases her statement on observations of social IBC businesses that very successfully unlocked funding from a number of private foundations (apart from bi- and multilateral donors) (interview P3).

Finally, in line with the findings in the analytical part, the expected predominance of IBC projects is reflected in the contributions from climate funds and the carbon market, as financing from these sources was directed overwhelmingly to IBCs. Several large-scale projects for IBCs worth hundreds of millions of dollars have been approved by or submitted to the green climate fund while no LPG project is in the pipeline to the best of my knowledge.[90] The same is true for carbon markets. Unlike IBC projects, programs that promote the use of LPG for cooking have secured finance in only very few cases so far. According to an Alliance-catalogue of selected projects to promote clean cookstoves and fuels, for instance, only a single project out of 56 promotes LPG (Clean Cooking Alliance, 2015). The project 'Darfur Low Smoke Stoves

[88] This is also due to the specific instruments available to (development) banks. They work with loans and finance infrastructure, thus the fragmented household energy sector is not their regular business.

[89] The SEforALL analysis of asset types and activities funded does not differentiate between different providers and the survey invitations to major foundations remained unanswered.

[90] E.g., a World Bank-led project worth $80 million which aims to disseminate IBCs to more than 17 million beneficiaries in Bangladesh (approved 2018), or another large-scale IBC program in Bangladesh, Kenya and Senegal worth 75 million, submitted by the German GIZ. For more information see https://www.greenclimate.fund/projects/fp070

Project' started disseminating LPG stoves in 2010.[91] More recently, the French NGO Entrepreneur du Monde has implemented two projects to expand access to LPG through microfinance that are approved for carbon credits in Burkina Faso and Haiti (Bruce, Aunan & Rehfuess, 2017).[92]

Understanding the strategies of development banks and multi-donor initiatives requires a closer examination of the preferences and influence of bilateral donors that contribute to these programs. The survey and personal interviews therefore inquired directly about the role of donor preferences from the perspective of organizations that implement clean cooking programs or channel donor support through their funds.

In the online survey, only 16 % of the experts indicated explicitly that their organization obtains significant funding from donors that prefer to support improved solid fuel stoves rather than LPG. These results may not be very conclusive because the question does not apply to some of the organizations surveyed (e.g., if they are donors themselves or if they are not involved in projects themselves). We can nevertheless conclude that for those organizations that mainly promote IBCs, donor preferences do not seem to be the major driver.

Yet, in individual comments and personal interviews, several experts from development banks and multi-donor partnerships emphasized that the bilateral donors funding their programs prevent investment – or an increase thereof – in LPG projects. The World Bank high-level representative of the clean cooking programme especially highlights the role of ministerial involvement within the donor country administration:

> I mean it's not an issue for the World Bank [to promote LPG], but it is [an issue] for some donors, if the donor comes for instance from the department of climate change or the department of renewable energy. LPG is not counted as renewable energy. So when they provide the funding – I mean, even though they are interested in [the] clean cooking space – because of their department mandate they cannot provide funding to LPG. (Interview P1, amendments in parentheses are by the author).

Similar tendencies can be observed for EnDev, which has been identified by several respondents as being governed by donors that wish to focus on improved biomass stoves (survey response S30, interview P4). But opinions within the organization differ, and recently donors have been engaging in discussions and some piloting activities on LPG. A specialist from the Norwegian development agency NORAD describes his country's position as generally "more open" to LPG than others, given its status as an oil producer. However, Norway provides its funds to EnDev through a budget line for renewable energies and consequently, the vast majority of projects financed through this fund must be for renewables (interview P4).

Evidence from these interviews hence supports the hypotheses on at least an indirect or implicit influence of funding agencies. They suggest that first, the focus on biomass stoves in

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[91] Interestingly it won a "Momentum for Change"- award from the UNFCCC in 2013 for its contribution to delivering climate friendly finance. For more information see https://mer.markit.com/br-reg/public/project.jsp?project_id=103000000002416

[92] For more information see: http://www.entrepreneursdumonde.org/downloads/EdM-StakeholderConsultationReport0612112.pdf

several major programs can be attributed to the influence and preferences of the donor countries who are funding them. Second, donor preferences for renewables are related to the fact that within donor country administrations, contributions to energy access programs are co-financed and managed by ministries that have a mandate to promote renewable energy.

The experiences of senior energy specialists from the IDB support this argument, as they report that their bank's possibilities to access concessional resources for LPG projects are restricted due to donor preferences. In particular, climate finance is seen as an important driver by experts from the IDB:

> […] the concessional resources we have access to […] many of them are linked to climate change. So that is when it becomes a problem, because if you say "ok, I want to do that, to support these LPG stoves because they are an adequate solution and people cannot afford them", and so on, the Climate Fund will be reluctant to do that. (Interview P2).

In this context, the IDB experts report the specific case of a funding proposal submitted to the NAMA facility, which is a joint initiative by several European donors.[93] An IDB climate change specialist collaborated with the government of Guatemala, which wished to promote LPG as an option for cooking in areas where LPG is available. The original proposal was not approved, since "[…] the issue of funding fossil fuels brought a lot of noise to them." Finally, the LPG component had to be removed (interviews P2, P7).

Trends

Is the current state of resource allocation indicative for the future or can we expect a change in the role of LPG? Asked about changes and plans in the past and future 5 years respectively, experts from development banks, public health agencies, and clean cooking platform initiatives report experiencing LPG slightly increasing in importance. The statements of bilateral donors and aid- and environmental organizations contrast this. With few exceptions, the experts from these organizations state that they do not perceive any previous or future changes in the role of LPG.

In the personal interviews, however, several experts point out that some donors are beginning to support programs that rely more strongly on LPG and other modern fuels. One example is the UK's development agency DFID that launched the *Modern Energy Cooking Services (MECS)*[94] program promoting electricity and LPG. Another case is UNDP's new Program of Activities in DRC to promote LPG and improved stoves in an attempt to reduce unsustainable wood fuel use (interviews P1, P3).

Since the perception of experts within an organization is not necessarily identical with the political strategy of the organization, the survey also inquired about the political viability of increased efforts to promote LPG in their organization. Close to 30 % of the experts believe that the decision makers in their organization are likely to favor a strategy that has a stronger

[93] The following donors are involved: German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU), UK's Department for Business, Energy and Industrial Strategy (BEIS), Danish Ministry of Energy, Utilities and Climate (EFKM), Danish Ministry of Foreign Affairs (MFA), European Commission. Information: https://www.nama-facility.org/about-us/

[94] Information on MECS can be found here: https://www.mecs.org.uk/challenge/.

focus on LPG in the future. It is mostly representatives of health and clean cooking organizations and development banks who tend to believe that their organizations are more likely than not to move in this direction. Staff in aid agencies, and development, energy and environmental NGOs tend to be uncertain or believe that this is rather unlikely. In total, 40 % are not sure and 29 % believe that decision makers are not likely to increase efforts to promote LPG.

As an interim assessment, it can be said that some key actors, particularly multilateral development banks and clean cooking initiatives, have been placing more emphasis on technologies and fuels that meet high emission reduction standards in the past few years, including LPG. At the same time, the focus of (particularly European) donors and NGOs has been to largely continue exclusively promoting biomass stoves, with a stronger focus on more advanced, less polluting technologies such as pellet stoves.

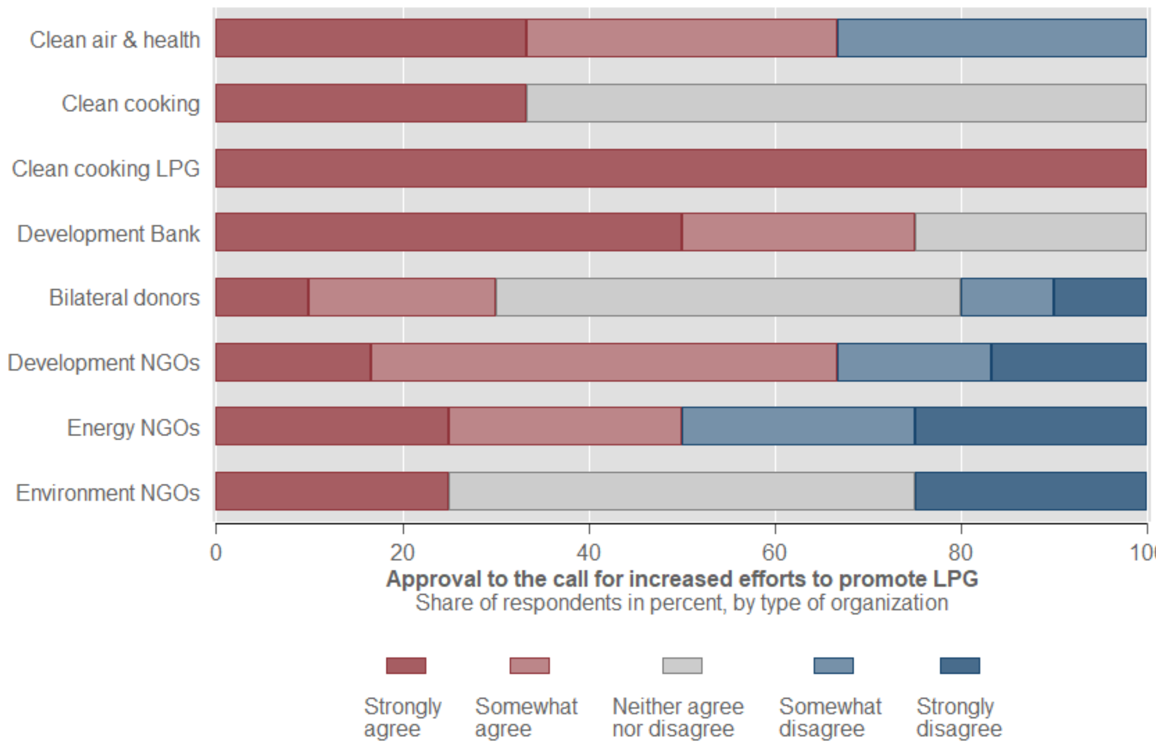
Views on increased efforts to promote LPG

Finally, how do professionals in the sector assess the focus of clean household energy programs today? Experts' views on increasing LPG-promoting efforts vary widely. In the survey, they were asked to indicate to what extent they agree with the argument that instead of a continued focus on improved/advanced biomass cookstoves, there should be increased efforts to promote the adoption and use of LPG. Overall, almost half of the respondents agree somewhat or strongly with this and believe that more LPG should be promoted. On the other hand, no less than 29 % are indifferent and 23 % tend to disagree rather or strongly to such a call.

Figure 9 illustrates how views on a potentially stronger LPG focus of clean household energy programs differ across types of organizations. Not surprisingly, support is strongest among organizations with a mandate to promote LPG or health, whereas general clean cooking organizations tend to be rather supportive too (somewhat agree). Among organizations with a general development mandate, support is strongest among development banks. Bilateral donors, development NGOs and organizations with an environmental interest are more sceptical.

The fact that half of the experts in the sector appreciate increased efforts to promote LPG, while only one third thinks this is an option favoured by decision makers in their organization, underpins the political character of spending decisions in the sector, which was also emphasized by several experts (survey responses S8, S10, interview P3).

Figure 9 Views regarding the focus of clean household energy programs



Note: Respondents were asked to what extent they agree with the following statement: "Some argue that instead of a continued focus on improved/advanced biomass cookstoves there should be increased efforts to promote the adoption and use of LPG." In order to avoid distortions, only one answer was included from organizations with multiple respondents. However, the aggregate result is not dependent on who is excluded, as the excluded answers to the relevant questions were either the same as those taken into account or left blank. 'Clean cooking' stands for clean cooking platform initiatives such as clean cooking alliances, whereas the answers from the Global LPG Partnership ('Clean cooking LPG') are shown separately for more accuracy. 'NGO energy' stands for NGOs, think-thanks or social businesses that are specialized on energy and sustainable development (with an energy focus).

6.4 Discussion and Conclusion

To mitigate the adverse effects of traditional biomass cooking for human health and the environment, development cooperation has been promoting access to more efficient and cleaner alternatives for a long time. Most recently, development thinking has somewhat shifted towards clean options such as LPG, yet it has been asserted that major donors largely continue to promote IBCs, which usually cannot sufficiently reduce indoor air pollution.

This chapter shed light on the contrasting positions of donors towards intervention for clean cooking. It sought to explain what determines their support for LPG versus IBC interventions by examining what economic incentives and political norms emanate from the relevant institutional framework for this sector and how these incentives and norms shape donor decisions. Major institutions in the global arena include the UN Sustainable Development Goals within the Agenda 2030, internationally formalized standards for the performance of cookstoves, and the international climate agreements, with mechanisms for public climate finance and carbon offsetting. To understand priorities in donors' ressource allocation, the study further examined the beliefs and values underlying donor preferences and considered the role of governance arrangements within the national and multilateral organizations involved in the allocation of resources in the sector.

Regarding the allocation of funds in the sector, evidence from the literature and the self-collected data from surveying representatives in the sector suggests that some key actors have been placing more emphasis on technologies and fuels that meet high emission reduction standards in the past few years, including LPG. In this respect, it can be concluded that the internationally formalized cookstove performance standards and the measurement approach that international organizations employ for tracking progress in energy access (SDG 7.1), both placing great emphasis on the cleanest alternatives, have in part directed the allocation of funds in the sector towards clean appliances and fuels, including LPG.

At the same time, support for LPG remains substantially below the efforts that might be expected given its scope to reduce the global health burden from indoor air pollution, and survey results indicate that this will not fundamentally change in the near future. One reason for this is that the above-mentioned guidelines are non-binding, while the institutional framework of climate policy provides strong economic and political incentives for improved biomass stoves, especially for bilateral donors who are key players in the sector.

On which empirical observation this finding is based and how diverging priorities of actor groups may be explained by the differently weighted influence of institutional elements and ideational factors is discussed in more detail below.

The evidence from the online survey and personal interviews suggests that organizations with a coordination and advocacy mandate in the sector, health-focused organizations, and development banks are generally open to all cooking technologies and aim to base their strategies increasingly on stove performance standards and empirical results while taking into account the specific context of the area in question. As a result, the resources that these organizations devote to the promotion of LPG as well as to other clean fuels and technologies might be expected to rise to some extent in the coming years. In view of their mandate, health organizations' position is self-evident. Turning to the rather positive attitude of development bank staff towards LPG, it can be assumed that, due to their professional background (many are economists) and because they are subject to fewer political and economic constraints than bilateral donors, they are more likely than the latter to base their program design on technical performance criteria.

However, as confirmed in the online survey among experts and in personal interviews, the resource allocation of major multilateral programs and initiatives like ESMAP, EnDev or clean cooking platform initiatives is also determined by the preferences of the bilateral donors who are funding them, either directly or sometimes via climate funds.

The focus of these (particularly European) bilateral donors as well as NGOs has largely remained the exclusive promotion of biomass stoves. Among these players, the increasing importance of performance standards for cookstoves has apparently led to a stronger focus on more advanced, less polluting technologies such as pellet stoves. However, the majority does not consider supporting LPG and is opposed to its increased promotion.

These donors' approach is understandable if one considers that the *weighting of institutional elements* is different for them than for health-oriented organizations and development banks. Being co-signatories of the international climate agreements, or as organizations dedicated to promoting environmental protection and sustainable development, many of these actors have a primary interest in combating climate change and in interventions that pursue an integrated approach to development and climate goals. In particular, they do not consider increased investment in gas production to reduce energy poverty to be compatible with the long-term objective of mitigating climate change. Therefore, in these organizations, emission reductions and the promotion of renewable energy are given more weight than health aspects.

The empirical analysis of public climate finance and carbon offsestting instruments, of financial flows, and of interviews, provided additional evidence on the *mechanisms* by which international climate policy provides political and economic incentives for a continued focus on biomass. That said, the future of market-based instruments is currently uncertain, as negotiations on Article 6 of the Paris Agreements have not yet been concluded.

Politically, development policy is expected to support the emission reduction targets to be achieved domestically and abroad and to be consistent with both political norms, like fuel subsidy reductions, and with the public interest.

Economically, since bilateral donors have restricted means, it is rational to provide support to residential energy-access projects through climate finance, emission reduction certificates, or budget lines tied to climate goals or the promotion of renewables. This allows the most cost-effective use of restricted public funds by contributing to commitments and targets in the areas of development and climate action at the same time. Climate finance and carbon credits are built around the primary goal of climate mitigation, giving priority to biomass cookstoves or other technologies based on renewable energy sources. The qualitative evidence from personal interviews supports this expected link for climate finance. Several experts confirmed that a significant part of the funding for household energy projects comes from donors' budget lines dedicated to combating climate change and promoting renewable energies, and that these funds cannot, of course, be used for LPG.

Carbon credits are another – historically very important – financing source for clean cooking projects. NGOs, for instance, can secure substantial additional funding for their IBC projects through emission certificates sold on the carbon markets. Regarding LPG, while a switch from non-renewable biomass to LPG leads to emission reductions, the detailed analysis of the relevant methodologies in this chapter revealed that there are only very limited opportunities to generate carbon credits in corresponding projects.

However, in personal interviews, experts stressed that there are also *practical aspects* of clean cooking interventions that shape donors' priorities for IBCs. The promotion of IBCs primarily involves the distribution of low-cost appliances, whereas promoting widespread and sustained LPG use commonly requires large-scale investments, a strong policy push from the national government and coordinated action of public and private entities on the national and international level.

In view of all these political and economic factors and their mutually reinforcing nature, it is easy to see why IBC interventions are much more appealing from a donor perspective. Consequently, the major donors in the sector hardly support LPG projects on the grounds of avoiding a carbon lock-in. However, the lack of support for LPG and the way the problems and solutions surrounding clean cooking are politically framed as well as the way in which financing mechanisms are designed lead to a different type of lock-in. That is, the transition to clean alternatives is being delayed, as attention and capital remains focused on other, less efficient products, namely improved biomass cookstoves.

That said, several countries are promoting improved access to LPG themselves. The Indian government in 2016 launched one of the most important of these programs. Within the context of this program, the following chapter examines the effectiveness of a measure to achieve sustainable LPG consumption.

7 HEALTH AWARENESS AND THE TRANSITION TOWARDS CLEAN COOKING FUELS: EVIDENCE FROM RAJASTHAN[95]

Programs in development cooperation that aim to provide access to clean cooking energy, have been placing very little emphasis on LPG. As shown in the previous chapter, this is partly because coordinated and strong support measures by national governments and industry are needed to build up the infrastructure required for the distribution of LPG and to help overcome the financial barriers for households. However, there are also important complementary measures that could be funded through aid funds. In our research presented in this chapter, we are testing the effectiveness of such a measure as a complement to a large-scale government program to promote LPG in India.

7.1 Introduction

In India, the health burden from traditional cooking is particularly high, with estimated 482,000 premature deaths annually attributable to household air pollution (Health Effects Institute, 2019). As a consequence, in 2016, the Indian government started the *Pradhan Mantri Ujjwala Yojana (PMUY)* program to provide poor households with access to LPG. As compared to combustion of traditional biomass, the combustion of LPG only generates a negligible amount of byproducts that are noxious to human health (see 4.1.2). As the PMUY covered the upfront cost for the access to this clean fuel, the number of households registered as LPG users increased by 80 million within just over 3 years. This is a development of unprecedented scale.

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[95] This chapter is largely identical to the following research article: Zahno, Martina; Katharina Michaelowa, Purnamita Dasgupta & Ishita Sachdeva (2020) Health awareness and the transition towards clean cooking fuels: Evidence from Rajasthan. *PloS one* 15(4): e0231931 (https://doi.org/10.1371/journal.pone.0231931).
Author contributions:

Martina Zahno: Conceptualization, methodology, data curation, formal analysis, project administration, data analysis, funding acquisition, investigation, validation, visualization, original draft preparation, review & editing.

Katharina Michaelowa: Conceptualization, methodology, formal analysis, project administration, supervision, funding acquisition, investigation, original draft preparation, review & editing.

Purnamita Dasgupta: Conceptualization, methodology, project administration, supervision, funding acquisition, review & editing,

Ishita Sachdeva: Investigation, project administration, review & editing.

If all these households fully switched to this clean cooking fuel, this would substantially increase the life expectancy in rural India. However, so far, many households who adopted LPG under the program continue to rely on traditional biomass for a major part of their cooking. Multiple fuel use (or fuel stacking, see also 4.1) is a widespread phenomenon and may persist over a long time (Cheng & Urpelainen, 2014; Heltberg, 2004; Masera, Saatkamp & Kammen, 2000). A study based on multi-year LPG sales data from Karnataka shows that PMUY beneficiaries buy less than half the amount of LPG cylinder refills as compared to general consumers in rural areas (Kar et al., 2019).

There may be different reasons for this, notably the cost of regular refills and supply-side constraints (Cheng & Urpelainen, 2014; Jain et al., 2015). In addition, households may simply not be aware of the important health benefits of LPG and may thus not recognize any serious need for change. They usually see the time saving effects and the convenience of LPG, but this alone may not prompt them to switch to LPG as their primary cooking fuel. Hence, providing clear health information could be key to inducing the transition to sustained use of clean cooking fuels.

Related literature has shown that information on health benefits does not necessarily change people's behavior (Beltramo et al., 2015; Mobarak et al., 2012). Yet, to the best of our knowledge, this has never been tested in the concrete context at hand. The closest literature relates to LPG use in Kerala and Uttar Pradesh (Krishnapriya, 2017) and willingness to pay (WTP) for improved biomass stoves in rural Bangladesh (Mobarak et al., 2012), where upfront costs were relatively high and constituted an important barrier (see also Bensch & Peters, 2015). This study now examines the effect of health messaging in a context where the problem of high upfront cost is already taken care of through the PMUY. We expect that under these new conditions, the effect of health messaging on WTP and LPG consumption may be substantial.

Our evidence is based on a survey of 554 households in the rural part of Bikaner district in Rajasthan. We randomly assigned health information to one part of the respondents and general, non-health-related information on LPG to the other part. We then measured the treatment effect on two variables: (i) the necessary financial compensation to induce households to double their LPG consumption at given prices, and (ii) the actual increase in consumption, measured by the households' use of a voucher for a new refill before a given deadline. The two separate measurements allow us to distinguish the effect of health messaging from the potential nudging effect of the voucher itself. In our study we did not measure any direct health outcomes. However, the health benefits of regular LPG use are uncontested and do not depend on maintenance or the way the stove is used (which in contrast, would be highly relevant for an evaluation of improved biomass cookstoves).

Overall, our experimental evidence suggests that health messaging is highly effective and should be included in the campaigns to promote LPG. Our results show that even very brief and simple health messaging has a sizeable effect. We also discuss why it may be useful to target not just women, but also men. Moreover, our results confirm that without the additional health information, only very few people are aware of the severe health risks they incur by cooking with traditional biomass.

The remainder of this chapter is organized as follows: in 7.2 we provide an overview of the extant literature regarding the effect of health messaging on household fuel choice and cooking habits. We then develop the conceptual framework (7.3) and present the sampling strategy and methodological approach, including the experimental set-up (7.4). This is followed by the presentation of our results in 7.5 and 7.6. Section 7.7 concludes with policy insights from the study.

7.2 Health awareness and fuel choices – Literature review

While there is an extensive literature on household fuel choice decisions in low- and middle-income countries (see 4.1) there are only a few studies examining the effect of health messaging on households' decision making in this respect. Furthermore, these studies focus on improved biomass cookstoves rather than LPG.

What we can draw from the extant literature is that (1) generally, knowledge about the health hazards of traditional cooking is very limited, (2) the effect of health messaging seems to be context dependent, (3) the effect in the context of transition to LPG has hardly been examined yet, and (4) has not been examined at all in the context of the PMUY program implemented by the Indian government.

Lacking knowledge about health hazards

Available evidence from several countries in Sub-Saharan Africa and South Asia (including India) suggests that the knowledge about the health hazards of traditional cooking in the affected population is very poor. While a majority of households recognize that there may be some health effects of household air pollution (Jain et al., 2015; Mobarak et al., 2012), they largely underestimate the severity of these risks (Mobarak et al., 2012; Nwankwo et al., 2018). When confronted with information about the fact that the adverse effects of household air pollution go way beyond transient irritations of eyes and throat, but substantially increase the risk of several deadly illnesses, they consider this information as highly salient (Beltramo et al., 2015).

The existing knowledge gap may be an important hindrance for the greater uptake and use of clean cooking fuels in India and elsewhere in the world (Jain et al., 2015). To bridge this gap, the most natural intervention is to provide information (i.e., health messaging). Given that the knowledge gap is so profound, the effect of providing information may be substantial.

No consistent evidence for the effect of health messaging

The few studies that have examined the effect of health messaging on household cooking fuel or technology use in a systematic way are primarily related to the introduction of improved biomass cookstoves. These stoves have often not been well accepted by households though, which is also true for India, where the adoption of improved biomass cookstoves has been limited (Khandelwal et al., 2017). Correspondingly, there is little evidence for any positive effect of health messaging on the willingness to pay for such cookstoves. In an experimental study in Uganda, only in one out of multiple settings do the messages increase willingness to pay, conditional on specific payment modalities. The direct reaction to payment modalities is much stronger (Beltramo et al., 2015). Similarly, a broader study on fuel change in Myanmar finds no significant effect of health counselling (Tun et al., 2005), despite the fact that significant changes in the relevant knowledge are observed (see Barnes, 2014 for a review of these and other related studies). In contrast, findings from survey data from urban Indian households suggest that the belief that wood does not cause pollution significantly increases the quantity of firewood used (Gupta & Köhlin, 2006).

Overall, the evidence suggests that the effect of health messaging depends on both technological features and financial constraints. Correspondingly, results from a survey-based study in China suggest that health messaging alone may not be effective unless it is coupled with access to improved technology in the form of culturally well-adjusted stoves (Jin et al., 2006). A randomized control trial in Bangladesh leads to similar conclusions (Miller & Mobarak, 2015). Other experimental studies highlight the importance of financial constraints, notably in the form of liquidity constraints preventing the purchase of costly investment goods in Bangladesh and Uganda (Beltramo et al., 2015; Mobarak et al., 2012). This is in line with the fact that those studies providing the most convincing evidence for successful health messaging interventions tend to consider situations in which large upfront costs do not exist. They look beyond the purchase of new technology and focus on behavioral change such as taking children out of the kitchen or cooking outside or with open doors rather than in a closed room (e.g., Barnes, Mathee & Thomas, 2011).

Insufficient evidence in the LPG context

In the specific context of LPG use, there is almost no evidence on the role of health messaging. A notable exception is the field experiment by Krishnapriya (2017) that covers the effect of health messaging with respect to LPG uptake and multiple other household choices of fuels and appliances in rural communities of the Indian states of Kerala and Uttar Pradesh. Households were confronted with information at different levels of intensity. It turned out that even the most intensive information campaign involving posters in the village, leaflets and one-to-one explanations to representatives of each household did not lead households to switch towards cleaner fuels, except for Kerala in those cases in which the information was provided to women. In contrast, with regard to electric appliances (such as the purchase of LED bulbs) the information treatment led to significant results. As purchasing a bulb requires a much smaller investment than purchasing an LPG stove, an explanation of the different reaction could be that LPG uptake is largely determined by liquidity constraints or financial constraints more broadly. This would be in line with the findings on other interventions discussed above.

New situation as upfront costs are covered

If the above reasoning is correct, the introduction of the government's PMUY program in 2016 should have significantly changed the situation by removing the major constraint for the spread of the LPG technology. By offering LPG connections to poor rural households, the large upfront cost is taken care of by the government. *LPG connection* hereby refers to the establishment of a formal account with a distributor as well as to the actual connection of the LPG stove to the LPG cylinder with a hose and a regulator. At current prices, this LPG connection comes to ₹1600 Indian rupee (about $25 U.S. dollar), and the additional cost for the first cylinder and the LPG stove is about ₹480 and ₹1020 respectively, i.e., another ₹1500. Total upfront cost hence amounts to around $50, which is difficult to bear for poor rural households.

In the context of PMUY the government completely takes over the cost of the LPG connection, and in addition, it provides the opportunity to purchase the first cylinder and the LPG stove on the basis of an interest-free loan granted by the distributors that is gradually repaid by an increase in the price of subsequent refills by approximately ₹170. Since no repayment is required if further refills are not purchased, households generally consider the initial uptake of the new technology as free of charge.

As mentioned in the introduction, this opportunity to receive an LPG connection, stove and the first cylinder initially free of charge has already driven 80 million households to adopt the new technology. If financial constraints are no longer binding, health messaging could now have a substantial impact on actual LPG use.

Of course, for a poor rural household, even the purchase of a refill for ₹480 (or more if some of the loan costs for the stove and the first cylinder are added to the bill of the refill) still represents some investment. Hence, financial constraints that prevented the uptake of the technology before the PMUY may still prevent some of the poorest households from purchasing refills for the LPG cylinder. The fact that domestic LPG consumption has been growing at a much lower rate than what could be expected from the huge increase in connections may be a result of these remaining financial constraints (Jain et al., 2018; Kar et al., 2019). To what extent health messaging increases LPG consumption under the new financial conditions thus remains to be tested.

7.3 Conceptual framework

We propose an illustrative utility-maximization model to motivate and structure our analysis. Let us assume that a household derives its utility from energy services, which require cooking gas or other fuels as input, and from other goods. The different fuels used to provide energy services are imperfect substitutes as they also differ on a number of other utility-relevant factors, notably health. To arrive at a simple model that allows a focus on LPG, let the household's utility U be defined as a function of the cooking gas LPG (g) and a composite good (x). The composite commodity x represents the sum of all other consumption goods, including traditional biomass for cooking such as firewood. To ensure a certain degree of both complementarity and substitutability between g and x we use a standard Cobb-Douglas utility function:

$$U(g,x) = g^{\theta} x^{1-\theta} \tag{1}$$

with $0 < \theta < 1$.

The parameter θ captures the preference for cooking gas as compared to the composite good, and we assume that it is non-zero since all households we consider opted for an LPG connection through PMUY and stated that they intended to purchase a refill at some point in the future. For an income level of B and prices p_g and p_x, the budget constraint is given as:

$$gp_g + xp_x \leq B \tag{2}$$

Solving the optimization problem yields the Marshallian demand for LPG:

$$g^*(p_g) = \frac{B}{p_g} \cdot \theta \tag{3}$$

This equation shows the household's optimal LPG consumption as a negative function of the LPG price p_g. We can invert this function to obtain an expression of the price the household is willing to pay as a function of the amount consumed, for given preferences and budget:

$$p_g(g^*) = \frac{B}{p^*} \cdot \theta \tag{4}$$

The first (rather trivial) observation to note is that since $\frac{\partial p_g}{\partial g} < 0$, if a household is asked to consume more than $g *$, the price it must pay will have to be reduced. What we are interested in here is how health messaging affects first, the discount a household demands when asked to consume substantially more LPG and second, the propensity of the household to actually increase consumption when provided with a pre-defined discount. Given the setting underlying our study, in which all households still have considerable leeway for more frequent LPG use, a consumption increase of 100 % is used to indicate substantially higher consumption.

In the following, we first develop the theoretical expectations for the household's willingness to pay for LPG conditional on increased use, and then derive the predictions for the propensity to double gas consumption.

WTP conditional on increased use

Let us consider that the preference for LPG θ is composed as follows: First, a basic preference $\overline{\theta}$ due to the convenience, time savings and other general benefits associated with cooking on the gas stove. Second, an additional appreciation based on the health benefits, reflecting knowledge of the health risks related to cooking with traditional biomass h, and the extent γ to which this knowledge is salient for the decision maker. In particular, the salience γ may vary based on the exposure to smoke from the traditional cookstove (*chulha*), and thus be higher for women than for men. Consequently, we define θ as:

$$\theta = \bar{\theta} + h \cdot \gamma \tag{5}$$

with $0 < h < 1$ and $0 < \gamma < 1$.

Now consider that we do not ask for the price households are willing to pay for their currently optimal – but very limited – consumption, but for a substantially increased consumption, namely a fixed $\bar{g} = 2g^*$.

Including the specification for θ and this fixed consumption requirement into Equation (4), we obtain:

$$p_g(\bar{g}) = \frac{B}{\bar{g}} \cdot \theta(h, \gamma) = \frac{B}{\bar{g}} \cdot (\bar{\theta} + h \cdot \gamma) \tag{6}$$

Taking the derivatives of $p_g(\bar{g})$ with respect to h and the cross-derivative with respect to h and γ provides us with the relevant theoretical predictions $\frac{\partial p_g}{\partial h} > 0$ and $\frac{\partial^2 p_g}{\partial h \partial \gamma} > 0$ (for computational details, see Appendix E).

We thus expect to find two effects: (i) a positive effect of the health messaging on the price the individual is willing to pay for LPG, and (ii) a positive interaction effect with salience, i.e., in particular, a greater effect of the health messaging on women than on men.

Equivalently, we can express these hypotheses in terms of the compensation required by the individual to increase LPG consumption from g^* to $\bar{g}$. The necessary compensation (C) corresponds to the market price of an LPG refill (p_m), which we can consider as given for our period of study, minus the price the individual is willing to pay (p_g), i.e., $C = p_m - p_g$. Hence, the effects with respect to the necessary compensation ($\frac{\partial C}{\partial h}$ and $\frac{\partial^2 C}{\partial h \partial \gamma}$) correspond to the above derivatives of $p_g(\bar{g})$ multiplied by (-1).

While our experiment allows us to test the effect of h, the evidence we can provide on γ is suggestive only, since our experiment was not designed to examine heterogeneous gender effects. This will be discussed further in the empirical part.

The propensity of doubling gas consumption

Let us now consider actual change in consumption. This change can be observed through the use of a price-reducing voucher until a pre-defined, household-specific deadline. More precisely, the outcome variable of interest is the propensity of the household to use a voucher that ensures an increase of LPG consumption from g^* to $\bar{g}$ for any level of a randomly determined price reduction D and the resulting offer price $p_d = p_m - D$ specified on the voucher.

Let us denote voucher use by the indicator variable Y. Whether or not the voucher is used depends on the difference in utility ΔU between a situation in which the voucher is used U_1 and a situation in which it is not used U_0:

$$Y = \begin{cases} 1 \; if \; \Delta U > 0 \\ 0 \; if \; \Delta U \leq 0 \end{cases} \tag{7}$$

The difference in utilities itself reflects the (unobserved) propensity of voucher use. Taking into account the conditions for voucher use, namely doubling initial consumption and the discounted price p_d, ΔU can be expressed as:

$$\Delta U = U_1 - U_0 = \bar{g}^{\theta}(B - \bar{g}p_d)^{1-\theta} - g^{*\theta}x^{*1-\theta}. \quad (8)$$

To predict how the propensity to use the voucher will be influenced by health messaging, and how this in turn is affected by the salience of this information for the decision maker, we again compute the derivative with respect to h and the cross-derivative with respect to h and γ. This yields the relationships: $\frac{\partial \Delta U}{\partial h} > 0$ and $\frac{\partial^2 \Delta U}{\partial h dy} > 0$ (see Appendix E).

The model thus predicts that, just like the WTP, the propensity to use the voucher (and hence the propensity to double consumption) should be positively affected by health messaging, and that this effect should again be greater for decision makers for whom the health information is more salient, namely for women.

7.4 Empirical analysis

7.4.1 Sampling and survey implementation

We tested our hypotheses in the rural communities of Bikaner, a district in the state of Rajasthan in Western India (see also the map in Appendix F). The selection was purposive as it fulfilled several criteria: Rajasthan was one of the first states to experience the launch of PMUY in May 2016. This means the program had been in its implementation phase for more than one year before the beginning of our survey in October 2017, so that the number of beneficiaries was sufficiently high for our sampling purposes.

Furthermore, available statistics on fuel use indicate that the district is quite representative for other parts of India (see Table 4). At 29 % for Bikaner district as a whole, the use of LPG in 2011 was exactly at the Indian average. In rural areas, however, access to clean cooking fuels was somewhat lower than elsewhere in the country. As shown in Table 4, 5 % of the rural population in Bikaner district used LPG as their main cooking fuel in 2011, as compared to 11 % in rural India as a whole. Consequently, there is also a stronger reliance on solid fuels like firewood and dung cakes that are used as an alternative. With respect to more general poverty-related indicators that may be relevant to fuel choice, Bikaner lies again at or somewhat below the country average. For instance, per capita income is almost equal to the national average, while access to electricity and literacy rates are lower in Bikaner than in the rest of India.

The sex ratio is clearly below the Indian mean, which suggests that the status of women in the region is rather low (for a discussion, see, e.g., Drèze & Sen, 2013). There is, however, a general North-South divide with respect to this indicator, and the rate we find for Bikaner district is close to the rates for the large Northern Indian states (GOI, 2013-14).

Table 4 Energy access and demographics, Bikaner vs. India 2011

	Bikaner		India	
	Total	Rural	Total	Rural
LPG main cooking fuel	29%	5%	29%	11%
Firewood main cooking fuel	53%	75%	49%	63%
Dung cake main cooking fuel	14%	16%	8%	11%
Electricity for lighting (%)	59%	40%	67%	55%
Average literacy	65%	61%	74%	69%
Sex ratio (women per 1000 men)	905	903	943	949
Net domestic product p.c. (INR)	52263		53331	

Sources: (Directorate of Census Operations Rajasthan, 2014; GOI, 2012, 2013-14; Government of Rajasthan, 2017).

The sample consists of 554 households who received an LPG connection under the PMUY program but remained infrequent users. 55 villages were sampled from the census lists (GOI, 2013-14) with probability proportional to population size. For each village, a simple random sample of ten households was drawn from the village lists of PMUY beneficiaries. On average, there were 133 PMUY beneficiaries living in each village in the sample. Power calculations and the sampling procedure are described in Appendix F.

The sampling strategy with many villages and relatively few households within each village was chosen to ensure that all interviews could be run in parallel so that spillover effects would be minimized. Households that were unavailable, impossible to trace or that turned out to be ineligible for our sample were dropped and replaced from a back-up list of replacement households at the time of the first visit to the village. No repeat visit was made to a village.

Within each household, the preferred respondent was the main cook, who is usually a female. However, men were accepted as respondents if the relevant women were unavailable or unable to communicate to the enumerators for cultural reasons. Eventually, there were about 10% male respondents in the sample (see Table A 14 in Appendix G).

At the outset, preliminary screening questions were asked as follows:

- Is the household indeed a PMUY beneficiary?
- What is the frequency of use of cooking gas (LPG)?

These initial questions allowed us to screen out households that did not fit our criteria for infrequent use. We defined the corresponding threshold at a yearly LPG consumption of less than 6 cylinders a year for a family of five (excluding toddlers). An average Indian family using LPG exclusively requires 10 to 12 cylinders per year (Kar et al., 2019). Thus, all PMUY households consuming less than 1.2 standard-size (14.2-kg) LPG cylinders per capita (for persons of age 6 and above) per year are considered infrequent consumers. Households covering all energy needs for cooking with LPG generally have a 50 to 100 % higher consumption in the sampled villages (Desai & Vanneman, 2015).

The responses to these questions were verified by checking the entries in the respondents' official gas passbooks that report the households' average LPG consumption per year and the date of purchase of the cylinder currently in use. This information allowed us to compute the expected time until the next refill would become due based on past consumption patterns.

It should be noted that a number of initially selected villages and individual households had to be replaced in the sample: First, for some of the originally sampled villages, we were unable to obtain the list of PMUY beneficiaries. Second, in some villages, a very large number of households could not be traced as villagers were away for agricultural operations and had moved into so-called 'dhani', i.e., shelters in the fields scattered around the village. When this number became very high (over 30 %), the whole village was replaced. Third, certain villages close to the India-Pakistan border were replaced due to security concerns. Eventually, the survey covered a total of 554 individuals from 55 villages.

Between September 2016 and March 2017 we carried out team building activities, some initial training of enumerators, a focus group discussion, pilots and key informant interviews to understand the situation on the ground and to refine our survey instruments. Subsequently, we established the cooperation with LPG distributors, requested the PMUY lists and analyzed secondary data sources from the Census and the National Sample Survey (NSS) as relevant for our sampling procedure. In October 2017 we conducted a final one-week intensive training workshop for the enumerators. The training included sessions on the rationale of the research design, exercises of the interviews including the implementation of the WTP-elicitation mechanism and the presentation of the different frames for the experiment (see below). It also included a familiarization of the enumerators with the use of the survey application (Qualtrics) that allowed them to directly register all answers on electronic devices like tablets or smartphones. Based on this training, the enumerators---a team of students from Bikaner Agricultural University---carried out the data collection between October 2017 and February 2018. All household interviews were conducted in Hindi or Rajasthani (Marwari).

The survey had several domains. The first section inquired extensively on household demographic and socio-economic characteristics while the second part focused on specific questions to understand cooking and fuel use patterns. Subsequently, the survey application randomly assigned the health information to the households (probability = 0.5), while the others received some general information on LPG supply and its characteristics. Following this, the enumerators assessed the required compensation for an increased use of LPG. Finally, the survey included several questions to test whether the respondents understood the health information provided.

The experimental set-up and the mechanism used to obtain the value of the required compensation are described in detail below.

7.4.2 Experimental set-up

The intervention consisted in verbal information on the effect of traditional cooking on child development and diseases such as lung diseases, heart diseases and eye diseases. The enumerators were given a pre-formulated one-page text on these issues that they familiarized with and memorized in advance, so that they would keep their wording very close to the text without directly reading it out. The duration of the presentation of health hazards lasted for 3 - 5 minutes.

Given the possibility that any frame – or simply the time spent on talking about LPG – may affect the answers of the respondents (Haffert, Reinke & Rommel, 2017), we constructed an alternative non-health related (and in this sense 'neutral' or placebo) frame for the control group. This frame consisted of information on how cooking gas is extracted or produced from crude oil and then distributed to the households. The time spent on the information was similar for both frames.

To illustrate the verbal information, the enumerators carried along colored plasticized picture cards (size A4). We selected images that would be as neutral as possible while visually clarifying the spoken text. An English translation of the pre-formulated texts for both treatment and control group as well as a copy of the corresponding picture cards are presented in Appendix H.

By design, the comparison of households who receive the health message and households who receive the placebo treatment reflects the net effect of the health messaging. If communicating about LPG over a certain time indeed has an effect by itself, the gross effect of health messaging (encompassing the effect of both the health-relevant content and the time of the LPG-relevant communication) should, in fact, be larger. As a consequence, our estimates of the treatment effect can be considered as a lower bound of the effect of health messaging for a population that would otherwise receive no LPG-related information at all.

After exposing the respondents to either of the two frames (health and non-health), we first assessed the households' stated WTP for LPG conditional on increased use and then observed households' actual consumption behavior by monitoring effective voucher use. Details on the measurement of these outcome variables are provided in the following sections.

7.4.3 WTP conditional on increased use

There are several procedures used in experimental economics to measure willingness to pay in a way that ensures that rational individuals will reveal their genuine preferences. We base our WTP assessment for LPG on the Becker-DeGroot-Marschak (BDM) mechanism (Becker, Degroot & Marschak, 1964), a widely used option that mimics a Vickrey auction by replacing the other buyer with a random number. Under a common version of the BDM method, the person states a *bid* (for a good to purchase). The bid is then compared to a randomly determined *offer price*, that is, the price at which the good is made available to the bidding person. If the person's bid is higher than the offer price, the item is sold at the offer price. If the bid is below the price, no transaction happens and no payment is made. In this context, revealing one's true willingness to pay through the bid is a strictly dominant strategy.

In a study on willingness to pay for water filters in northern Ghana, Berry, Fischer & Guiteras (2019) demonstrated that the mechanism can be usefully applied even in contexts of low numeracy among the respondents. To ensure that our respondents really understand the process, we explained each step of the procedure and followed it up by carrying out two rounds of the BDM mechanism with unrelated goods, first with a piece of soap, and then with a lighting bulb. If the respondents' bid was higher than the offer price, they paid the offer price and received the goods. Hence, by the time the respondents reached the LPG assessment, they were quite familiar with the procedure and had experienced that the implications of their decisions were real and binding.

With respect to LPG, the implementation of the BDM mechanism required adjustments due to the specific context of the study. First, real transactions with LPG cylinders are not possible, since LPG supply regulations in India imply that households can only purchase the refill from official distributors of oil marketing companies, and that, too, only once they have used and returned their empty cylinder. Hence, instead of concluding the transaction by selling an LPG cylinder at the reduced offer price to successfully bidding respondents, we handed out vouchers for the purchase of the next cylinder.

Second, we aim to elicit the WTP for LPG not as a good used only rarely for special occasions, but on a more regular basis, i.e., under the condition of *increased use*. This cannot be achieved simply by providing households with the offer to buy an additional cylinder. As our sample only includes households that plan to buy a refill at some point over an infinite time horizon, all of them should be willing to purchase one at the market price p_m.

To obtain the relevant information on the WTP for increased consumption, the additional LPG use must be observable during a pre-specified period, i.e., before a certain deadline. As mentioned earlier, we chose a deadline relative to current use. More specifically, we fixed a specific deadline for each household that would require this household to consume the remainder of the LPG in the cylinder currently in use twice as quickly than under normal circumstances (see Appendix H for calculation details). The expiry date was clearly communicated to the respondent and written on the voucher. We also monitored that it was respected by the distributors.

We thus asked the respondents to make their bid for a new LPG cylinder under the condition of using up their current cylinder until the deadline. This bid was then compared to the randomly drawn discounted offer price p_d. The corresponding discount D over the market price p_m of ₹480 was designed to fall in the interval between ₹5 and ₹235. Larger discounts were not expected to be necessary. The offer price itself was then between ₹245 and ₹475 and drawn from number cards in front of the respondents (for details, also on the choice of the price range, see Appendix I).

When the respondents stated a WTP which was at least as high as the offer price, and hence the (offered) discount (D) was greater than or equal to the required compensation for the increased use of LPG, they received the voucher, and they knew that they were expected to buy the next cylinder before the expiry date indicated on the voucher (see full protocol of WTP elicitation mechanisms as well as details on vouchers in Appendix H).

Unlike in the prior examples with the soap and the light bulb, we could not enforce, however, the final sale. This violates the conditions of the BDM mechanism because stating a bid that reveals the true required compensation is then no more a strictly dominant strategy. Indeed, it does no harm to consumers to make a higher bid since if they bid high enough to get the voucher, they do not need to make actual use of it. At the same time, it does not make them any better off to place a higher bid than the one that corresponds to their genuine willingness to pay. Hence revealing the truth remains a weakly dominant strategy.

In any case, a rational respondent will never make a bid that is too low. If at all, WTP will hence be overestimated by the procedure we chose. This may add to the effect we could obtain due to the fact that people under both the health and the alternative frame were confronted with some discussion on LPG (see above). For both reasons, average WTP obtained in our survey can be considered as an upper bound of the respondents' true WTP.

Note that the estimate of the health messaging effect should not be biased due to the enforcement problem. This is because there is no reason to believe that it might affect the treatment and the control group in different ways.

7.4.4 **Increase in LPG consumption**

In the second part of our empirical analysis, we compare the actual voucher use by the households in the treatment and in the control group. Since the vouchers could be used only until the expiry date, the use of the voucher implies that the household truly consumed the remaining LPG in their current cylinder more quickly than usual, and that the incentive of the discount on the next cylinder was sufficiently strong to trigger this behavioral change. In addition, actual voucher use provides some insights into the sustainability of the initial impression made by the health messaging.

Two distinct factors should be considered in this context:

First, while most of the time, the health information is only transmitted to the female respondent who also provides the statement on WTP, the choice to double LPG consumption or not is the result of an intra-household decision-making process involving several household members. The actual purchase is usually carried out by men. These male family members (i) do not directly obtain the health message and (ii) will usually be less smoke-exposed than their spouses. Unless the information is transferred within the family very convincingly, this should reduce the effect of health messaging. Furthermore, the effect of health messaging should depend on the power of the respondent within the intra-household decision-making process.

Second, over time, the impression made by the health messaging may simply fade away. In the most extreme case, the information could be fully forgotten, in which case the intervention would have a zero effect on voucher use. In contrast, sharing health information and discussing it among family members may also increase its influence on the purchasing decision due to further reflection upon the topic, and respondents may develop a stronger preference for LPG when they are continuously exposed to the toxic smoke from the chulha after having learned what this exposure implies for their health. Depending on which of these causal channels dominates, health messaging may have a stronger or weaker effect on actual consumption behavior. The effect may also be stronger or weaker than what the respondents' immediate reaction measured in terms of their WTP may lead us to expect.

7.5 Results

In a first step, we test whether our randomization allows us to successfully split the sample into two groups that are similar in all aspects that could be relevant for WTP and voucher use. Table A 12 in Appendix G compares the means of both groups for a number of variables including socio-economic characteristics such as the respondents' age, education, religion, household size, their social category and proxies of income and wealth such as assets and land ownership.[96] Further variables describe the households' fuel choice and cooking behavior and capture preferences for and access to LPG: The average consumption of LPG, distance to the LPG sales point (zero in case of home-delivery), perceived convenience of LPG, knowledge about LPG subsidies and stated barriers to regular LPG consumption such as high refill costs or safety concerns. Finally, there are variables directly related to current LPG use and the conditions under which respondents were bidding, such as the number of days until the voucher's expiry date (voucher validity) and the content of the current cylinder at the time of the survey. Across all 25 variables, none of the differences in means is statistically significant at the 10 % level. This implies that potentially confounding factors are well balanced across the two experimental groups.

The same holds if we limit the sample to those respondents who obtained a voucher (see Table A 13 in Appendix G). Apart from a small difference in the share of Hindus and Muslims, the two experimental groups only differ with regard to WTP for LPG, which is a desired effect of our intervention. A description of all variables and summary statistics are provided in Table A 14 in Appendix G.

7.5.1 Impact on willingness to pay

Given the successful balancing of potentially confounding variables, we can now compare WTP for the treatment and the control group. Overall, the health messaging leads to an average increase in WTP of about ₹10 (from ₹352 to ₹362, see Table 5 below).

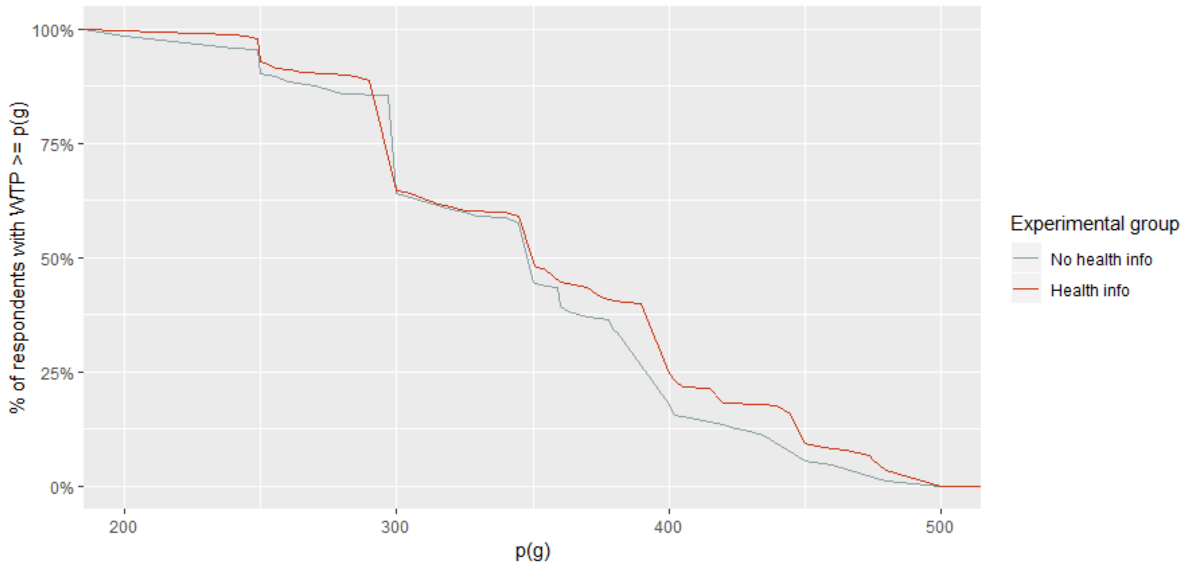
The effect is not large, but the intervention was only very short and carried out by enumerators that were strangers to the respondents. Under conditions of more sustained health messaging by trusted health workers or members of the local community, the effect might have been much stronger. Furthermore, remember that the estimate reflects the net effect of health

[96] The data and code required to replicate all findings reported in this chapter is available here: https://doi.org/10.1371/journal.pone.0231931.s006.

messaging, and that the gross effect could be larger if the time of the communication on LPG has a positive effect by itself.

To provide some more detail on this result Figure 10 displays the cumulative distribution of the respondents' stated WTP in both treatment groups.

Figure 10 WTP for LPG conditional on increased use, by experimental group



The share of respondents that accepted prices in the upper half of the price range is consistently higher among subjects who were confronted with the health information. Figure 10 also shows that the estimated median WTP is at ₹350 per cylinder. Since these estimates must be considered as an upper limit of the true WTP of our respondents (see 7.3), they are well in line with the results of an earlier large-scale household survey in six Indian states, which suggest that households who are interested in adopting LPG would be ready to pay ₹300 per month (median) to cover all cooking needs with LPG (Jain et al., 2018). While health messaging increases WTP, substantial additional subsidies will still be required to induce poor households to become more regular LPG consumers.

Apart from the direct effect of our intervention and the respondents' price-elasticity of demand, their stated WTP may be influenced by some additional factors. In particular, our previous discussion suggests that gender differences due to differences in smoke exposure and time spent cooking should affect the impact of health messaging.

It may also be relevant to control for the content of the current cylinder and the time left until the voucher needs to be used. Few households had a full cylinder at the time of the survey, such that the requirement to speed up consumption referred to different absolute quantities. Households might agree to a lower compensation when their cylinder is already partly used. Similarly, the absolute time period over which the behavioral change to double LPG consumption is required varies between households. Due to differences in the usual speed of consumption, this may be true even if the filling of the cylinders is initially the same for two households. In principle, this could have implications for WTP, too. For instance, households might feel that a behavioral change over a small period of time – maybe maybe just a few days – is easier to achieve than a change over many weeks. In this case, WTP should be higher if the survey happens closer to the date at which the next refill would have been required anyway. However, one could also imagine that having more time enables the household to plan the increased consumption in a better way, i.e., by using LPG rather than the chulha when many guests are in the house, which may not happen that frequently. Moreover, time preference would imply that a compensation to be received in the far away future would be valued less than a payment one could receive within a few days.

Whether these considerations do affect the respondents' stated WTP, and if so, in which direction, will be examined below. We will also add further controls for potentially relevant household characteristics.

7.5.2 **Multivariate regression analysis for WTP**

Table 5 presents the results with Column 1 as a baseline, a dummy variable for male respondents and its interaction with the treatment variable in Column 2, and a number of key control variables in Columns 3 and 4.

While Column 1 shows the already discussed effect of the intervention without any other variables, in Column 2 we distinguish between the effects for male and female participants of our survey. As mentioned already, there are only few male respondents in our sample and they systematically differ from average men in the communities of interest. In most cases, these men belong to very traditional families, as they did not allow their spouses to talk to the enumerators. This also suggests a highly unequal balance of power in these households. Our sample therefore does not allow us to provide general estimates for heterogeneous treatment effects between women and men. Yet, it is important to understand to which extent the specific households in which we interviewed men rather than women are different, and thus affect our results. Furthermore, the differentiation by gender within our sample can provide some suggestive evidence as a basis for the analysis of gender effects in future research. These considerations lead us to systematically present whatever suggestive results we have, calling for verification in future studies.

Note that due to the inclusion of the interaction term, the coefficient estimate for health messaging now refers to female respondents alone. With a point estimate of about ₹14 it is higher than the average for all respondents (male and female) in Column 1. Correspondingly, the negative coefficient of the interaction term suggests that men in our sample react to health messaging much less than females. In other words, at least for the specific selection of male respondents in our sample, results are in line with our expectations. The main effect of the dummy for male respondents further indicates that within our sample, men generally state a much higher WTP than women. This seems to be a common result for WTP assessments in households in which women are not used to committing to major payments, and does not specifically relate to LPG (see also Beltramo et al., 2015). In our sample, only 3 % of women report taking decisions on the purchase of durable goods on their own.

Table 5 Treatment effect on WTP, including controls

	(1)	(2)	(3)	(4)
Health message	10.237*	13.777**	12.175**	13.166**
	(0.065)	(0.013)	(0.036)	(0.046)
Male		31.863**	54.111***	42.714**
		(0.014)	(0.001)	(0.014)
Health message X Male		-41.385*	-62.277**	-53.083*
		(0.072)	(0.020)	(0.068)
Voucher validity			-0.283	-0.298
			(0.178)	(0.199)
Content			4.245	5.845
			(0.766)	(0.698)
Asset index				0.342
				(0.906)
Land				15.647**
				(0.029)
LPG distance				-0.170
				(0.673)
Fin. restriction				-14.355
				(0.172)
Education				3.402
				(0.289)
Age				-0.341
				(0.316)
Household size				-0.853
				(0.574)
Months since LPG adoption				-0.191
				(0.645)
Constant	351.678***	348.846***	352.230***	366.083***
	(0.000)	(0.000)	(0.000)	(0.000)
N	539	539	468	455
Adj. R^2	0.003	0.008	0.017	0.019

* $p<0.1$, ** $p<0.05$, *** $p<0.01$. p-values based on standard errors clustered at village level in parentheses. For the additional variables in Columns 3 and 4 complete data is not available for the full sample, resulting in a smaller number of observations.

Column 3 then adds controls for the remaining content of the cylinder at the time of the survey, and the period of validity of the voucher. Neither of the two are significant. This suggests that neither variable plays a major role in determining the compensation for increased consumption requested by the household. Rather, households seem to just consider the required change in behavior in terms of the relative increase in consumption, no matter the period over which this change is requested, and no matter what absolute quantity of LPG consumption this implies.

Column 4 further adds a number of other control variables that might be relevant for the willingness to pay. The only significant variable is the dummy for land ownership, reflecting that wealthier households owning some land tend to have a higher WTP. Note that the effects of the control variables (or the lack thereof) should not be over-interpreted as some of them are highly correlated. They are included mainly to show the robustness of the main results. The estimated treatment effect remains positive and significant throughout (with little change in size across Columns 2 to 4 in which it refers to females).

7.5.3 Impact on voucher use

So far, the results thus confirm our hypotheses. But is the voucher that allows the household to buy the next LPG cylinder at or below the price of reported WTP actually used? Does it indeed lead to the requested behavioral change of doubled consumption until the given deadline? Overall, in 303 out of 539 conducted BDM procedures, the respondent's bid (i.e., stated WTP) was sufficiently high to receive a voucher. The voucher values, i.e., the discounts offered on the purchase of the next LPG cylinder, range from ₹5 to ₹235, and about 70 % of them lie above ₹150. For 296 vouchers handed out to households we could trace whether the beneficiary had used the voucher to cover a part of the household's next LPG purchase.

It turns out that only 35 % of these 296 households actually used the voucher. Unfortunately, we are unable to disentangle the different possible reasons discussed above, and any combination of these could be responsible for this result. What we can examine, however, is the extent to which our intervention, namely the health messaging, affected the actual use of the voucher.

Effect of health messaging on voucher use among voucher owners

Given the binary nature of the dependent variable, we proceed with logistic regressions presenting both odds ratios and predicted probabilities. For comparison, the supporting information of this study's online publication[97] further includes the code for linear probability models, which show very similar results. Just as in our analysis of WTP, we first present a simple bivariate estimation of the treatment effect and progressively add more variables.

Based on the 296 available observations, we find a strong and significant effect of health messaging on voucher use. Table 6, Column 1 indicates that the odds of using the voucher are 1.63 times higher for households that received the health message. This corresponds to an increase in the probability of voucher use by 0.11, from 30 to 41 % (see also Table 7). The treatment hence increases the probability of voucher use by more than one third.

[97] Available here: https://doi.org/10.1371/journal.pone.0231931.s006.

The effect is even more remarkable given that quite some time passes between the treatment and potential voucher use, and given the required intra-household transfer of the information. In addition, since spill-overs between the treatment and control group cannot be avoided during the period until voucher use, this result represents a lower limit of the actual effect. Finally, as before, we should remember that we only estimate the net effect of health messaging, not including the possible impact of LPG-related communication time, which was the same for both treatment groups.

Table 6 Treatment effect on voucher use, including controls

	(1)	(2)	(3)	(4)
Health message	1.628** (0.047)	1.396 (0.198)	1.633* (0.083)	1.950** (0.029)
Male		0.885 (0.826)	1.004 (0.995)	1.569 (0.515)
Health message X Male		8.379** (0.030)	5.948* (0.087)	4.280 (0.190)
Voucher validity			1.002 (0.880)	0.999 (0.963)
Content			0.460 (0.312)	0.379 (0.228)
Asset index				1.076 (0.473)
Land				1.231 (0.504)
LPG distance				1.025* (0.088)
Fin. restriction				1.702 (0.127)
Education				1.012 (0.931)
Age				0.981 (0.325)
Household size				0.878* (0.098)
Months since LPG adoption				1.038* (0.055)
WTP for LPG				0.995** (0.033)
Constant	0.429*** (0.000)	0.435*** (0.000)	0.524** (0.030)	4.362 (0.226)
N	296	296	254	247
Area under the ROC curve	56%	58%	62%	72%

Logit models with odds ratios, * $p<0.1$, ** $p<0.05$, *** $p<0.01$. p-values in parentheses. Lack of data on the additional variables included in Columns 3 and 4 lead to a reduction in the number of observations.

Columns 2 to 4 of Table 6 add a differentiation by gender of the respondent and further controls. Due to the interaction term with the dummy variable for male respondents, odds ratios shown for health messaging in these models refer to female respondents only. In contrast to theoretical expectations, it seems that the positive and significant overall effect is now primarily driven by the few male respondents in our sample. The interaction term itself, which shows how much the effect of health messaging differs between male and female respondents, is strong and significant in two out of three regressions. It indicates that for the male respondents, the odds ratio of health messaging is eight times as high as for the female respondents in our sample (Column 2). Adding further controls somewhat reduces this difference, but the estimate remains sizeable. Furthermore, for men alone, the treatment effect is always positive and significant (not shown), while this is not the case for female respondents (cf. Column 2). This is surprising since the male respondents in our sample initially did not seem to react to the treatment---as measured by their statement on WTP.

This suggests some interesting household dynamics after the visit by our enumerators. Due to their lack of power within the household, women might have more difficulties in transforming their initially voiced preferences into the household's final purchasing decision. Hence, even if their greater exposure to smoke leads them to react more strongly to health messaging in the first place, they may not always be in a position to actually push for a greater use of LPG. Men, once convinced, do not have this problem. At the same time, they seem to require more time to react to the health information received. They might first cross-check this information and/or discuss the issue within the family and with friends. This suggests that considering given power relations within rural Indian households, it is important to convince men about the health benefits of LPG, and not just women. Further research is required to examine heterogeneous effects of health messaging and intra-household decision-making on fuel choices.

Table 7 Predicted probabilities of voucher use

	No health message	Health message	Difference	p-value	N
Total	0.273	0.437	0.164	0.005	247
Females	0.266	0.401	0.135	0.026	225
Males	0.354	0.791	0.437	0.019	22

Estimates are based on the logit model presented in Table 6, Column 4.

Adding further control variables substantially improves the overall prediction of voucher use as indicated by the receiver operating characteristic (ROC) curve, notably in Column 4. In this specification, the estimate of the treatment effect is even higher than before. Table 7 presents the results of this model in terms of predicted probabilities, across experimental groups and gender of the respondents. It indicates that health messaging increases the probability of voucher use by 0.16 overall, which reflects the 14 pp increase when the health messaging was delivered to women, and a massive 44 pp increase for the few cases in which the messaging was delivered to men.

Regarding the individual control variables, there is no surprise. As before, many of them are insignificant, this time including the indicators we use for wealth and income. This is consistent with our model since household budget is as relevant for U_0 without the voucher as for U_1 with the voucher and hence cancels out for ΔU (see Appendix E). The significant control variables are distance from the sales point, household size, months since LPG adoption, and WTP.

The latter may deserve some additional explanation. The odds ratio for WTP is smaller than one, reflecting a negative relationship between WTP and voucher use. At first glance, this may seem unexpected. However, WTP is, by design, negatively related to the discount. Households obtain the vouchers only if their stated WTP is higher than the randomly drawn, discounted offer price. Hence, the higher this price (i.e., the lower the discount D), the higher their WTP must be for them to be included in the sample for the estimations in Table 6.

The latter also leads to a more general risk of selection bias, even when we control for WTP. The average WTP in the sub-sample of voucher owners is significantly higher than the WTP of those respondents who did not receive a voucher (₹390 versus ₹314). As a result, the sub-sample may not be representative of our initially drawn sample of typical PMUY users.

This problem also affects our estimate of the treatment effect. As the health messaging affects WTP, it also affects the selection into the sub-sample of voucher owners. Studying the treatment effect within this sub-sample will thus not provide us with a valid estimate for the full impact of our intervention.

7.5.4 Joint effect of health messaging on voucher use

In order to avoid the selection problem discussed above, we additionally estimate the *joint* effect of health messaging on voucher use. That is, we now use the total sample of respondents, no matter whether they obtained a voucher or not, and set the outcome variable *voucher use* to zero for those respondents who did not receive a voucher in the first place (as their WTP was below the randomly drawn offer price). The share of voucher users in the total sample of households in our sample is now 20 % (among voucher owners only, it was 35 %). We use a fixed effect for each offer price, as the chance to obtain a voucher with a given WTP increases with decreasing offer prices. The fixed effects will thus provide a substantial part of the explanation for the zero-values in the outcome variable.

Table 8 shows the results of logit models similar to those in Table 6. Without offer-price fixed effects, being confronted with the health message increases the odds of a household using a voucher (and thus demonstrating doubled consumption) by a factor of 1.44 (Column 1). This corresponds to an increase in the probability of using a voucher by 0.06, from 17 to 23 % (see code and data provided in online publication). While the absolute value of the increase is smaller than in the sub-sample of voucher owners (0.06 as compared to 0.11), in relative terms, the increase is thus as important as before. In both samples, the treatment increases voucher use by more than one third. By adding offer-price dummies in Columns 2 to 4, the overall quality of the prediction markedly increases as indicated by the area under the ROC curve. This reflects the relevance of the price effect. The estimate of the treatment effect also becomes more precise, and larger than before.

Table 8 Joint effect of health information on voucher use

	(1)	(2)	(3)	(4)
Health message	1.444* (0.095)	1.616** (0.046)	1.504 (0.111)	1.942** (0.026)
Male			1.484 (0.496)	2.450 (0.212)
Health message X Male			2.383 (0.263)	1.479 (0.674)
Content				0.351 (0.174)
Voucher validity				0.999 (0.915)
Asset index				1.078 (0.441)
Land				1.247 (0.468)
LPG distance				1.027** (0.049)
Fin. restriction				1.312 (0.437)
Education				1.035 (0.778)
Age				0.978 (0.220)
Household size				0.870* (0.056)
Months since LPG adoption				1.025 (0.174)
Constant	0.203*** (0.000)	0.461 (0.117)	0.428* (0.094)	0.922 (0.933)
N	532	465	465	396
Offer price fixed effects	No	Yes	Yes	Yes
Area under the ROC curve	55%	70%	71%	77%

Logit models with odds ratios, * $p<0.1$, ** $p<0.05$, *** $p<0.01$. p-values in parentheses. As some of the highest offer-prices perfectly predict failure to use the voucher, and as the additional control variables have some missing values, Columns 2 to 4 include a smaller number of observations.

In terms of the differences between male and female respondents in our sample, the results point in the same direction as before, but the interaction term is insignificant (Column 3). When including control variables in Column 4, our results suggest that health messaging almost doubles the odds of voucher use among the households with female respondents (odds ratio = 1.94). The point estimate for the few male respondents is again even higher, but the difference remains insignificant. Table 9 shows these effects in terms of predicted probabilities, for the whole sample and by gender of the respondents.

Table 9 Predicted probabilities of voucher use

	No health message	Health message	Difference	p-value	N
Total	0.167	0.267	0.100	0.011	396
Females	0.157	0.249	0.091	0.024	366
Males	0.287	0.490	0.202	0.215	30

Estimates are based on the logit model presented in Table 8, Column 4.

While we have so far used fixed effects to account for differences in the offer price, we can also include the offer price p_d directly as an explanatory variable. This also allows us to directly interpret the relationship between prices and voucher use (see Appendix I). In line with the predictions of our theoretical framework (7.3), we find that price reductions have a strong positive effect on the household's purchasing decision. Across all available observations, a price discount of ₹40 (8.3 % of the current subsidized price of a new cylinder) is estimated to increase the probability of voucher use on average by about 10 pp. This corresponds to the estimated impact of health messaging.

The effect of health messaging remains relatively stable across the range of discount values, and hence, there is little evidence that the two measures interfere with each other (see Figure A 9 in Appendix I). This implies that health messaging can be usefully topped up by price reductions to reach an even greater overall effect on demand.

7.6 Testing the information channel

While we argue that the success of the intervention is based on the respondents' greater health awareness, this has not been directly tested so far. In this last part we will thus assess the effect of the health messaging on health-related knowledge. To that aim, we compare post-intervention responses of the treatment and the control group to several questions regarding the health hazards related to traditional cooking (see Appendix H) for post-intervention questionnaire).

First, we examine the response to the question whether traditional cooking affects health slightly, severely, or not at all. Our dependent variable is a binary indicator of the belief that there are serious health hazards involved.

Without any further information, respondents knew very little about health hazards related to smoke from the chulha, leaving much scope for improvement: under the alternative frame, only 13 % believed that there were serious health hazards related to cooking with traditional biomass, while 60 % believed that there were just some minor transitory effects, and 27 % were of the opinion that there were no health effects at all.

This was also confirmed in complementary qualitative interviews with other households prior to the experiment. When women were asked about health effects, they primarily thought of these as temporary irritations such as coughs or watering eyes, and stated that these were not problems of any major consequence, but rather something to get used to over time. A comparison of our findings with previous surveys in India (Aklin et al., 2016; Desai & Vanneman, 2015; Jain et al., 2018) hence underlines the importance of enquiring specifically about knowledge of *serious* health risks. According to a large survey among rural Indian households in 2018 (Jain et al., 2018), 84 % of those who relied on biomass as primary cooking fuel stated that cooking with LPG is better than using a traditional cookstove regarding the health impact. This may be seen as indication that most households are aware of adverse health impacts related to using biomass. While this share is comparable to the proportion of households who are aware of *some* (major and minor) health impacts in our sample, the results from our more detailed questionnaire demonstrate that this is merely superficial knowledge and that the vast majority of these families lack awareness of the *severe* health risks related to household air pollution.

In the context of such limited initial knowledge, health messaging led to a strong and highly significant increase of reported awareness of serious health hazards. Among respondents that received the health information, 48 % report to be aware of serious adverse health effects, i.e., reported awareness is four times as high as before. The total share of individuals who reported to be aware of health risks (serious or less serious) increased to 94 %.

Table 10, Column 1 presents the results for severe effects, distinguishing by gender. Among female respondents, 12 % of the untreated report that they are aware of severe health issues as compared to 46 % (12 + 34 %) of the treated. There are no significantly different responses for male respondents. All results are robust to the addition of further control variables (not shown).

Of course, the treatment effect of the health message may be partly due to social desirability bias: after the information treatment, respondents know that a positive answer is expected and might hence pretend to be aware of severe health hazards even without fully understanding or being really convinced.

Table 10 Treatment effect on health awareness

	(1) Severe effects	(2) IAP diseases	(3) All diseases
Health message	0.343***	0.150***	0.066***
	(0.000)	(0.000)	(0.000)
Male	0.132	-0.176***	-0.115***
	(0.116)	(0.000)	(0.000)
Health message X Male	0.157	0.029	0.023
	(0.174)	(0.590)	(0.570)
Constant	0.118***	0.280***	0.482***
	(0.000)	(0.000)	(0.000)
N	503	539	539
Pseudo R^2 / Adj. R^2	0.140	0.096	0.084

Column 1 shows average marginal effects based on a logit model, as the dependent variable is binary. Columns 2 and 3 show linear regression models. * $p<0.1$, ** $p<0.05$, *** $p<0.01$. p-values based on standard errors clustered at village level in parentheses.

We thus consider a second dependent variable, which requires concrete knowledge about health hazards incurred when using traditional solid fuels for cooking. This variable reflects the share of diseases related to indoor air pollution (IAP) correctly identified within a set of ten diseases out of which only six are indeed related to IAP. Column 2 presents the results. They confirm those of the previous estimation. Our brief health message increases the share of correctly identified smoke-related diseases by 15 pp for female respondents---and similarly for male respondents since the interaction term is very small and statistically insignificant. Independently of the health messaging, in our sample, female respondents generally recognize diseases related to traditional cooking substantially better than male respondents.

As a third dependent variable, we examine the share of correctly identified diseases among all ten diseases. A value of one on this variable implies that not only the IAP-related, but also the IAP-unrelated diseases are correctly identified. This ensures that high values on the dependent variables cannot be obtained simply by responding in a way that relates all kinds of diseases to cooking habits. Hence the values of this variable cannot be driven by social desirability bias. When using this variable, the treatment effect is smaller (only about 7 pp), but remains highly significant (see Column 3). As before, the treatment effect does not differ between male and female respondents, i.e., there seems to be no difference regarding the capacity to absorb the health information we provide. But again, overall, women recognize the relevant diseases substantially better than the men in our sample. Unless the difference is driven by the particular selection of men among our respondents, this gives some plausibility to our expectation that women who are exposed to smoke on a daily basis may find the knowledge about smoke-related diseases more important than men. This could explain why they tend to be somewhat better informed already prior to our intervention.

In sum, the empirical evidence thus confirms that the intervention increases the respondents' knowledge about the health hazards related to traditional cooking. Despite some differences in initial knowledge, this is true for both women and men in our sample, with no observable difference in the treatment effect. This implies that the differences we observed between male and female respondents regarding the impact of health messaging on WTP and voucher use cannot be explained by differences in the capacity to absorb the information we provide. While additional research is required to confirm these results with a representative sample of women and men, this is in line with our theoretical argument, which suggests that gender differences should be driven by differences in the salience of the information rather than by the information itself. Of course, as we have seen, such differences may be overridden by practical constraints related to the limited power of females in household decision making over expensive items.

7.7 Conclusion

Traditional cooking habits based on the use of solid fuels such as cow dung and firewood affect a range of SDGs. In particular, they generate severe health hazards. With an estimated 846 million people being exposed to household air pollution in India, the corresponding health burden is particularly high (Health Effects Institute, 2019). This paper examined to what extent health messaging for poor rural households can mitigate the problem. Based on a survey in rural Bikaner district (Rajasthan), we analyzed the effect of a health messaging intervention on willingness to pay and the propensity to consume more LPG, a clean fuel, which all of our sample households already have access to in principle through the Indian government's PMUY program.

Our results show that health messaging increases the reported willingness to pay for LPG, and leads to substantially higher actual consumption among households who currently use LPG only on a very infrequent basis. We measure this based on a voucher which can only be used if LPG consumption is doubled until a certain deadline. Households exposed to health messaging use the voucher about 30 % more often than households exposed to a placebo treatment. We further show that the impact of our very brief, but concrete health messaging is as strong as a decrease in the price of a new LPG cylinder by about ₹40.

Obviously, health messaging does not need to be considered as an alternative to price reductions. Our results confirm prior studies indicating that the willingness to pay for regular LPG use by a typical poor rural household is considerably below the current regulated market price of ₹480 per cylinder. It may thus be useful to combine health messaging and price reductions. We find that these two measures do not interfere much with each other and can thus be decided upon independently.

Our results also confirm that the health messaging indeed increases the respondents' knowledge about smoke-related diseases, which is an important precondition for the causal effect we claim. It should be noted that without any health messaging, the relevant knowledge is extremely low. Among the untreated, only 13 % of all respondents believe that cooking with traditional biomass entails any serious health risks. This percentage increases to 48 % in the treatment group. The low initial knowledge may be one reason why we find such substantial effects on LPG use.

Our empirical estimation was not designed to estimate heterogeneous treatment effects between women and men. Nevertheless, our study suggests some potentially relevant, and partially unexpected gender differences that call for further investigation in future work. Independently of these results, given that women often lack decision-making power on major purchases, knowledge building should not target women alone.

8 CONCLUSION

Four years after the adoption of the Sustainable Development Goals (SDGs) progress has been made in some areas, such as in the eradication of extreme poverty. But, as noted by UN Secretary-General António Guterres, "it is abundantly clear that a much deeper, faster and more ambitious response is needed to unleash the social and economic transformation needed to achieve our 2030 goals" (UN, 2019: 2).

Taking effective action requires a strong knowledge base: scientific evidence plays a key role in identifying measures that may accelerate progress across the dimensions of sustainable development, in designing policies, and in evaluating their impact. It is particularly important to understand how individual goals are interconnected and recognize that transformative change can only be achieved through a systemic approach that seeks to maximize co-benefits while identifying trade-offs and mitigating their consequences. In my doctoral thesis, I seek to address some of these interlinkages.

The aim of my scientific work is to contribute to the knowledge in an area that is considered one of the most promising starting points for achieving the desired transformations related to the SDGs at the required scale and speed: energy decarbonization along with universal access (Independent Group of Scientists appointed by the Secretary-General, 2019: 75–83). Independent assessments of the global progress on the SDGs highlight the urgent need to transform the global energy system, with a fundamental shift in favour of renewables in the energy mix and a significant increase in energy efficiency. In the second half of the century, the global energy system is expected to have transitioned to net zero CO_2 emissions in order to meet the goals of the Paris Agreement, through carbon pricing and the phasing out of fossil fuel subsidies, amongst other things. At the same time, all stakeholders are requested to ensure universal access to modern energy services, notably by accelerating the provision of clean electricity and by prioritizing the shift away from polluting fuels and stoves to clean cooking solutions (ibid.).

Within this wide-ranging subject area, this dissertation has dealt with research questions in two fields of action that are interlinked with each other and in which progress has proved to be particularly challenging: first, fossil fuel subsidies, and second, access to clean cooking solutions. The following sections recapitalize my main findings and point out potential avenues for further research.

Research on fossil fuel subsidies is relatively novel but has grown rapidly in recent years. The scholarly and grey literature reviewed in Chapter 2 documents the enormous financial volumes of government support to the production and consumption of fossil fuels and provides evidence of their negative effects on the ecological, economic, and social dimensions of sustainable development. Universal fuel subsidies fail as a social policy instrument because they largely benefit the more affluent and create distorted economic incentives. In the energy sector, the volume of fossil fuel subsidies still dwarfs the support for renewable energies. Subsidies for fossil fuels provide incentives for the over-consumption of fossil fuels, and modelling studies and cost-examinations in selected countries show how subsidizing fossil fuels can threaten the economic viability of low-carbon energy.

In Chapter 3, this thesis complements this evidence with an empirical analysis on the aggregate level. In a study co-authored with Paula Castro, we examine whether – across countries – fossil fuel subsidies impede the deployment of renewable energy, taking into account policies that subsidize or otherwise support renewables. To that aim, we combine an extensive dataset on countries' renewable energy support policies with country-level estimates of fossil fuel subsidies and data on a range of further variables between 2003 and 2013. Using panel regressions, we estimate how the subsidy volume per capita is linked to the share of electricity generated from non-conventional renewable energy sources. Hereby, the initial stage of renewable energy deployment, i.e., a countries' likelihood to generate any electricity from non-conventional renewables at all, is examined in a separate model.

Our main findings provide empirical evidence that, across countries, higher subsidies for fossil fuels are linked to a significantly lower share of renewables in electricity production when countries already do produce grid-connected electricity from renewables (0.16 % for a 1 % increase in subsidies, on average). That said, our main estimations do not provide evidence for a direct adverse effect of fuel subsidy increases *within* individual countries. This is presumably because subsidies vary greatly between countries, while fluctuations within countries are limited and often lack a clear pattern.

Our results further confirm the positive effects of subsidies and other financial support measures for renewables, stringent environmental policy, and democratic institutions, as they all show consistent and substantially relevant links to higher renewable energy shares.

Regarding the initial stage of renewable energy deployment, our estimations suggest that the likelihood that a country produces *any* electricity from renewables is not directly related to the magnitude of fossil fuel subsidies. However, we do not believe that this finding diminishes the validity of our main results described above, as the decision to install the first facilities for electricity production from renewables alone does not necessarily reflect much of the cost differential between fossil fuel based and low-carbon energy technologies, respectively.

According to our estimations, country-level characteristics that have substantial and statistically significant effects in this initial stage of renewable energy deployment are the reliance of a country's economy on oil production, its potential for renewables compared to other countries, its general environmental performance and – again – its financial support policies for the deployment of renewables. Regarding direct support policies for renewables, we find that they substantially increase the likelihood that some part of a country's electricity is produced from renewable energy sources, whereas between-country differences surpass differences in individual countries, just as for fossil fuel subsidies.

Our study provides the first cross-country empirical evidence of the adverse consequences of fossil fuel subsidization on renewable electricity provision. As a policy-relevant insight we conclude that reducing fossil fuel subsidies and redirecting public spending towards investment in low-carbon technologies is likely to effectively benefit the further dissemination of renewable energy. Yet, our results do not allow us to identify a causal effect of subsidy policy within countries. Hence, further research is needed to strengthen the empirical evidence and to provide insights into causal mechanisms on the country level, taking into account the specific technological and policy environment. The data needed for such studies is likely to be of better quality in the future, as longer time series and probably also more comprehensive and accurate estimates of subsidies on fossil fuels will be available. The latter requires political will by national governments, however, to (at least) step up efforts to measure subsidies transparently.

Nevertheless, with this study, the thesis contributes to our knowledge of the diverse consequences of fossil fuel subsidies, especially from an environmental perspective. Understanding these effects and generating profound knowledge on how fossil fuel subsidies affect welfare and its distribution across population groups are key requirements for successful interventions and policy reforms.

In particular, the study adds to a growing body of research which documents that introducing policy measures to internalize carbon costs (including the removal of fuel subsidies) can also help to achieve other, complementary objectives in energy policy, such as increased energy security through the promotion of renewables. Beyond that, eliminating subsidies that encourage wasteful consumption of polluting fuels contributes to various objectives of sustainable development, including the protection of life on land (SDG 15), economic growth (SDG 8), and public health (SDG 3) through reduced air pollution. Reorienting resources spent on fossil fuels towards education or social security offers further benefits for vulnerable groups.

At the same time, there can be conflicts between the objectives of climate policy and those of energy- or development policy. Industry representatives, for example, sometimes express concerns about negative short-term effects of carbon pricing on the international competitiveness of firms or sectors. Moreover, carbon pricing (including the removal of subsidies for fossil fuels) can interfere with the objectives of affordability and distributive justice. These potential trade-offs are particularly challenging in low-income and emerging countries, since abolishing fossil fuel subsidies commonly increases prices for consumers, thus affecting affordability. The greatest burden can arise for poor households which may not be able to meet their basic energy needs if the consumption of energy is not subsidized in some form. This includes electricity for lighting and clean fuels and appliances for cooking, which are fundamental to human well-being and economic development.

Efforts to improve basic energy access in developing countries are the focus of the scientific work in the second part of this thesis. Here I zoom in and examine research questions specifically related to residential use of clean cooking systems, an area where progress has been very limited despite decades of effort.

Nearly 3 billion people still rely on polluting fuels like solid biomass or coal for cooking and heating. Burning these fuels on open fires or inefficient, often unvented stoves causes high levels of household air pollution. Due to the high emissions of health-damaging and climate-active pollutants, household air pollution is responsible for one of the most important global health burdens, has major negative effects on the environment and the climate, and impedes the economic and social prospects of women and girls. In view of the urgent need to reduce mortality from household air pollution and to mitigate climate change, it is of central interest for research and development practice to identify the technologies and strategies that are most promising to foster household transitions to efficient and clean cooking appliances and fuels at scale.

The literature review in Chapter 4 highlights how diverse and complex the barriers are that impede progress towards more widespread access and more frequent use of clean cooking solutions. They have much to do with poverty and therefore with the affordability of improved technologies, but also with limited opportunities for market development and a lack of access to a reliable supply. Also, consumers often do not value cleaner cooking technologies such as improved biomass stoves, biogas or liquefied petroleum gas (LPG) because the new appliances may not satisfy all energy needs, or because consumers are not aware of the air pollution caused by traditional cooking practices.

Chapter 5 of my dissertation traces the efforts in development cooperation and by national governments to provide widespread access to more efficient and cleaner cookstoves and fuels during the past four decades. It also shows how the focus of these efforts has evolved over time, along with the prevailing view on traditional biomass use and its consequences. The priorities of different actors in the sector today vary widely. In international development cooperation, there still appears to be a strong emphasis on improved biomass cookstoves, despite the scientific evidence that emissions from currently available biomass stoves are significantly more harmful to health than those from stoves that run on LPG, electricity, ethanol or biogas, as documented in the literature review in Chapter 4. The evidence discussed there also suggests that the contribution of improved cookstoves to climate change mitigation and other SDGs (like reducing poverty or achieving gender equality) may be limited, whereas there are even settings (such as those with high fractions of non-renewably harvested firewood) where LPG is likely to outperform improved biomass stoves in terms of climate change mitigation.

These results have sparked an international debate on where resources in the clean cooking sector should be directed to. On the one hand, it is generally well recognized that it will not be possible to ensure universal access to clean cooking systems (i.e., stoves and fuels that cause minimal health-damaging emissions such as electricity, biogas or LPG) in all parts of the world any time soon and that the combined use of stoves and fuels (including traditional biomass) will remain a reality for a long time to come. On the other hand, advocates of clean fuels believe the current focus of development cooperation on biomass stoves results mainly from a predominance of climate mitigation goals over health considerations. They call for a stronger focus on clean fuels, including LPG as a transitionary solution, until clean cooking systems based on renewable energy are available at scale. LPG can be disseminated on a large scale relatively easily and has been promoted in multiple national government programs.

In view of their potentially important development impacts, I seek to identify and explain these differences in current donor priorities for clean cooking interventions in Chapter 6, focusing on LPG and improved biomass cookstoves as the dominant options. In a theoretical analysis and empirical assessment of the clean cooking sector, I examine how key institutions related to the sector (in the area of health, climate policy, and development) on the global level are structuring actor behaviour through the economic incentives and political norms these institutions' characteristics provide. Thereby I also consider the governance arrangements in the sector as well as the values and ideas underpinning actor preferences. The analysis draws from public choice as well as from the literatures on the political economy of aid and on climate finance. It triangulates evidence with self-collected data from an online survey among key organizations in the sector, on the one hand, and from personal expert interviews, on the other.

I find that some key actors like development banks have recently redirected some of their funds to appliances and fuels that reduce polluting emissions to a minimum (including LPG), likely as a consequence of now internationally formalized cookstove performance standards and the tracking approach for energy access, which both place great emphasis on the cleanest alternatives to traditional cooking.

Yet, support to LPG remains substantially below the efforts that might be expected given its scope to reduce the global public health burden. The resource allocation of major multilateral programs and initiatives is strongly determined by the preferences of the bilateral donors who are funding them, either directly, or sometimes via climate trust funds. Bilateral donors, particularly the European ones, as well as NGOs largely continue to exclusively promote biomass stoves, even though the attention that more advanced, less polluting technologies receive has increased. These organizations attach more importance to reducing emissions and promoting renewable energy than to health aspects. In particular, they do not consider increased investment in gas production to reduce energy poverty to be consistent with the goal of mitigating climate change in the long term, which is why the majority of these organizations oppose increased support for LPG.

My analysis of the financing structure of the sector suggests that international climate policy provides strong political and economic incentives for a continued focus on biomass in the clean cooking sector. The channels through which climate policy shapes the priorities in the sector are first political, through emission reduction targets, and second economic, through the instruments of public climate finance and the carbon markets. For bilateral donors, in view of their restricted means, it is rational to provide support to residential energy access projects through public climate finance, through emission reduction certificates, or through budget lines tied to climate goals or the promotion of renewables. All these funding instruments are built around the primary goal of climate mitigation and are consequently designed in ways that prioritize biomass cookstoves or other technologies based on renewable energy sources. That said, as far as market-based approaches are concerned, it is currently uncertain how they will evolve in the future, as negotiations on new market mechanisms under the Paris Agreements (Article 6) have not yet been concluded.

One limitation of the study on donor priorities in the clean cooking sector is that it is not yet possible to precisely quantify the total donor contributions to the various technologies, mainly because of the complex financing structures, the partly privately organized sectors, and large data gaps. Moreover, due to the restriction of the analysis to LPG and improved biomass cookstoves, donor priorities and how they are determined might not always be captured in a comprehensive way. An analysis that considers all alternatives to traditional cooking available in this policy area might hence provide more generalizable findings on current donor priorities.

Nevertheless, my research enhances our scientific understanding of how donor countries allocate their resources, particularly regarding the allocation of official development assistance for climate policy activities. Michaelowa & Michaelowa (2007) noted that donor countries have used development funds at least partially for climate policy purposes for almost thirty years, whereas climate-related aid often contributes only indirectly, if at all, to poverty reduction. The evidence from my analysis of a specific policy field supports this finding. The authors' call for an explicit recognition of potential trade-offs between goals, a clear definition of priorities, and the commitment that development assistance is only invested in those climate policy activities that have a strong poverty-reducing impact is therefore as timely today as ever. Both international cooperation to reduce greenhouse gases and development cooperation to fight poverty and improve global public health are essential. It is, however, important for donors to make transparent the main objectives they pursue with interventions in the field of household energy and to finance projects that primarily pursue environmental and climate-related objectives through other budget lines. In the context of clean cooking interventions, there are already first studies that openly state environmental as well as health goals of clean cooking interventions and use analytical frameworks that integrate both goals to guide interventions (e.g., Rosenthal et al., 2018). This kind of analysis is particularly useful to examine how LPG and improved cookstoves could be optimally combined where widespread and exclusive use of clean fuels is not realistic in the short term.

While the international development community has been struggling to transform the cooking sector over the past decades, national governments have also been implementing interventions with the same goal. Some of them, including Brazil, Indonesia or Senegal, implemented major programs to promote the transition to LPG. The Indian government in 2016 launched one of the most important of these programs, the 'Pradhan Mantri Ujjwala Yojana', which aimed to expand LPG to rural areas. While it has led 80 million households to adopt LPG, a major fraction of these households continues to rely heavily on solid biomass for their daily cooking.

In a co-authored study with Katharina Michaelowa, Purnamita Dasgupta and Ishita Sachdeva, we evaluated how health-related information about the detrimental consequences of traditional cooking with biomass affects households' propensity to use LPG more regularly. Our experimental evidence from rural Rajasthan is encouraging. We show that health messaging increases the reported willingness to pay for LPG and substantially increases actual consumption. We measure this based on a voucher which can only be used if LPG consumption is doubled until a certain deadline. Households exposed to health messaging use the voucher about 30 % more often than households exposed to a placebo treatment. We further show that the impact of our very brief, but concrete health messaging is as strong as a decrease in the price of a new LPG cylinder by about ₹40.

Importantly, our results confirm prior studies indicating that a typical poor rural household's willingness to pay for an LPG cylinder under conditions of regular use is considerably below the current regulated market price. Health messaging should therefore not be considered an alternative to price reductions but may be combined with the latter. In view of the harmful effects of universal subsidies, it would be desirable to provide this assistance specifically to poorer households. Yet implementing a subsidy policy targeted in this way would pose a major challenge in both political and practical terms.

Our assessment of a brief health message hence contributes to strengthening the knowledge needed to inform interventions that aim to drastically improve clean cooking access, especially regarding the underresearched role of awareness. Due to our limited resources in this rather small project, our research is obviously constrained in terms of the period under study and the type of intervention. In order to inform effective policy measures, the evidence base therefore needs to be further strengthened by evaluating interventions that are even more realistic. For instance, it is important to understand the impact of information dissemination through local health workers, both immediately and on long-term fuel consumption behaviour. Experimental studies along these lines have already been launched.

Another area that deserves increased scholarly attention are the implications of gender differences in the context of information campaigns. Our study was not initially designed to estimate heterogeneous treatment effects. Nevertheless, our results suggest some potentially relevant and partially unexpected gender differences. In line with the gender-specific salience of cooking-related health hazards, we found that female respondents react much more strongly to health information than the male respondents in our sample when it comes to their stated willingness to pay. However, the estimated treatment effect on voucher use is greater for male than for female respondents. This suggests that until the final purchase of the next LPG cylinder, some interesting intra-household dynamics may be at play. These gender-specific outcomes may be important and call for further investigation in future work. Independent of these results, given that women often lack decision-making power on major purchases, knowledge building should not target women alone.

Overall, the scientific findings of this doctoral thesis underline the importance of integrated approaches to planning and evaluating energy transition measures that equally consider climate, development and health perspectives. Moreover, the insights from this thesis illustrate that in order to realize synergies between individual objectives and at the same time minimize the negative consequences of trade-offs, it is essential that we do not ignore the complexity of certain interlinkages. For instance, when promoting renewables, the role of barriers that are not directly visible, such as support for fossil fuels, needs to be factored in. Similarly, while subsidies on fossil fuels generally need to be eliminated due to their overwhelmingly negative effects, there are sometimes compelling reasons to subsidize energy in order to jump-start the market and reach poor consumers. A typical example is LPG for cooking.

Research based on such integrated approaches should be expanded in the future. It provides promising instruments to guide effective interventions in development and climate policy and reflects the fundamental idea of the sustainable development goals under the Agenda 2030.

APPENDICES

Appendix A Methodological appendix Chapter 3

Although hybrid models for multi-level analysis or analysis of clustered panel data are gaining ground in the methodological literature (e.g., Bell & Jones, 2015, Allison, 2009; Schunck, 2013), they are not widely used. This appendix provides (1), further explanations of the estimation procedure in a hybrid model and (2) illustrates how the resulting coefficients compare to those from alternative panel data models in the context of unobserved heterogeneity, such as correlated random-effects (CRE) models, standard random-effects (RE) or fixed-effects (FE) models.

A1 Estimating panel regressions for clustered data in a hybrid model

After specifying the variables to be analyzed in the model, we work with Stata's user-written command `xthybrid` (Schunck & Perales, 2017). It evaluates which of the variables vary sufficiently to create additional regressors, creates group-means and demeaned variables for these variables, and fits the hybrid model in an automated process.

Applying `xthybrid` on our sample and key set of covariates indicates that the variables *FF subsidies*, *RE policies*, *Democracy*, and *Net energy imports* (and *Environmental performance* in the binary part) can be used to estimate two separate effects. All other variables, including *OPEC*, *RE potential*, *Energy consumption* and *GDP p.c.* do not vary sufficiently within clusters (indeed, less than 1 % of the variance in these variables is within clusters) and are hence not used to create additional regressors.

The `test` option additionally provides tests of the random-effects assumption (that is, the within-cluster effect equals the between-cluster effect) for the individual regressors. In the second, linear part of the model, the formal tests of the random-effects assumption indicate that within-cluster effects and between-cluster effects are statistically different for *FF subsidies* ($p < 0.05$), *RE policies* ($p < 0.1$), *Net energy imports* ($p < 0.05$), and the share of electricity from hydropower. Hence, following Schunck & Perales (2017), we separate within- from between effects for these four variables and use the more efficient random-effects estimators for the other covariates (notably *Democracy*, *GDP p.c.* and *Energy consumption*). Unfortunately, the `xthybrid` command (including the test of the random-effects assumption) does not work for estimations in the first, binary part of our model, for some unknown reasons, which is why the centering of the variables and the estimation commands are performed manually for this part.

Analysis of variance within- and between-clusters and xthybrid's test command can nevertheless inform the model specification. They indicate that within- and between cluster effects differ significantly for *FF subsidies, RE policies and Environmental performance* ($p < 0.05$ or $p < 0.01$). Hence, separate effects for these covariates are estimated in the binary response model applied in the first part.

How do hybrid models compare to other models commonly used in the context of unobserved effects? To illustrate this, the following section presents the estimation results from our basic hybrid models in this chapter are, alongside with alternative panel data models used in the context of unobserved effects. For the first part with binary response models, the comparison of models and estimation methods focuses on whether and how the distribution of the (unobserved) heterogeneity is restricted. For the second part of our estimation, the linear panel regression, this appendix illustrates in more detail how the hybrid model compares to the correlated random-effects model and to standard random-effects and fixed-effects models.

A2 Hybrid and other binary response models for clustered data (part I)

Table A 1 shows estimation results from predicting the likelihood that country i generates a positive amount of electricity from non-conventional renewables in year t (corresponds to Column 1 in Table 1, Chapter 3.5.) Column 1 displays results from a linear probability model with fixed-effects, Column 2 those from a pooled (random-effects) probit model and Columns 3 and 4 those from hybrid models with pooled maximum likelihood estimation coefficients and with full maximum likelihood estimation from a panel probit model respectively. In models 1, 3 and 4, the coefficients of FF subsidies, RE policies and Environmental performance correspond to the within-cluster effects.

Manually calculated average partial effects (APEs) shown along with the coefficients are comparable across models. [98] Bootstrapped standard errors are calculated for the APEs in Model 3, but not for (4), due to prohibitive computation time.

In the linear fixed-effects estimation in Column 1, unobserved heterogeneity is allowed to be correlated with the covariates. The time-constant variables *OPEC* and *RE potential* drop out. Since the estimation of this model only captures the variation within countries, which is virtually negligible compared to the variation between countries, the model is not well specified. The resulting coefficients are therefore hardly comparable to those from the other models. The pooled random-effect probit model in Column 2 allows estimating the effects of time-invariant variables. It is based on the assumption that unobserved heterogeneity is independent from the covariates, which is why we would expect the coefficients to be larger than in the fixed-effects model. The APEs of several covariates now show large and significant effects. On average, having one more renewable energy support policy in place is associated with a 16 pp higher probability to produce electricity from renewables. In addition, a 10 point increase of

[98] Our data does not allow to estimate probit or logit FE models. In FE binary models, any group (i.e., country) with all zeros or all ones in the dependent variable is dropped out from the regression due to the lack of within-group variation. Our sample contains a very high number of countries without any variation in the dependent variable. In particular, many countries had zero electricity generation from renewable energy across the whole period analyzed in this study.

the environmental performance index (0 to 100) is associated with a 7 pp higher probability of renewable energy production. Furthermore, countries that are OPEC members are much less likely to produce any electricity from renewables (proability decreased by 0.38) and an RE potential which is increased by 10 million tonnes of oil equivalent (corresponding to about twice Switzerlands total power consumption) is associated with a 1 pp higher probability of renewable electricity production. The hybrid model in Column 3, just like Chamberlain's correlated random effects model, is based on the assumption that the unobserved heterogeneity is correlated with the covariates, however only through the mean of x. As a consequence, the coefficient of *OPEC* becomes somewhat smaller. The effects of the time-variant covariates *FF Subsidies, RE policies* and *Environmental performance* are now separated into within- and between-cluster effects, whereas the latter correspond to the coefficients on time-averages of these three variables. The between-cluster effect of *Environmental performance* is very similar to the coefficient of the covariate in the pooled model, while the within-effect is not significant, reflecting the dominance of between-cluster variation in the sample. For *RE policies*, the between-cluster APE is even larger than the estimate from the pooled probit. Applying the full (hybrid) maximum likelihood estimation with xtprobit in Column 4 essentially results in the same findings, even though some of the APEs are marginally smaller than in Column 3.

Applying the (mathematically equivalent) correlated random effects model instead of the hybrid model yields very similar results (not shown). Yet the coefficient of the time-averages corresponds to the difference between the within- and the between-cluster effect, which makes a meaningful interpretation difficult.

Table A 1 Binary response panel data models

Model	(1) LPM Fixed Effects	(2) Probit Pooled MLE		(3) Hybrid RE Probit Pooled MLE		(4) Hybrid RE Probit MLE	
	Coeff	Coeff	APE	Coeff	APE	Coeff	APE
FF subsidies p.c. (log)	0.000 (0.003)	0.033 (0.027)	0.008 (0.006)	0.010 (0.015)	0.002 (0.003)	-0.011 (0.153)	-0.000 (0.005)
RE policies	-0.002 (0.011)	0.693*** (0.129)	0.164*** (0.029)	0.003 (0.075)	0.001 (0.017)	-0.132 (0.358)	-0.005 (0.011)
Environmental performance	-0.013** (0.006)	0.028*** (0.011)	0.007*** (0.002)	-0.042 (0.026)	-0.009 (0.006)	-0.150 (0.176)	-0.006 (0.005)
$\overline{\text{FF subsidies p.c.(log)}}$				0.023 (0.036)	0.005 (.008)	0.174 (0.162)	0.007 (0.009)
$\overline{\text{RE policies}}$				1.152*** (0.218)	0.245*** (0.044)	5.572*** (0.598)	0.208*** (0.055)
$\overline{\text{Environmental performance}}$				0.028** (0.012)	0.006** (0.003)	0.125** (0.053)	0.005** (0.004)
Democracy	0.011 (0.014)	0.046 (0.041)	0.011 (0.010)	0.003 (0.045)	0.001 (0.010)	0.128 (0.182)	0.005 (0.008)
RE potential	–	0.005* (0.003)	0.001* (0.001)	0.004 (0.003)	0.001 (0.001)	0.028** (0.012)	0.001** (0.001)
OPEC	–	-1.614*** (0.528)	-0.382*** (0.118)	-1.633*** (0.597)	-0.347*** (0.145)	-9.409*** (2.290)	-0.351*** (0.180)
GDP p.c.(log)	-0.073 (0.159)	0.167 (0.119)	0.040 (0.028)	0.095 (0.125)	0.020 (0.028)	0.097 (0.469)	0.004 (0.026)
Log Likelihood	–	-608.606		-528.847		-153.993	
Observations	1444	1444		1392		1392	
Number of countries	161	161		155		155	
Year dummies	YES	YES		YES		YES	

Standard errors in parenthese. In the LPM, pooled probit and hybrid probit with pooled MLE estimation, standard errors are robust to arbitrary within-panel autocorrelation. BT standard errors were calculated for the hybrid probit models in (3) and (4). FF = fossil fuels. RE = renewable energy. $^{*}p < .1$, $^{**}p < .05$, $^{***}p < 0.01$.

A3 Hybrid and other linear models for clustered data (part II)

In the second part of our model, we use only observations with a positive amount of electricity from renewables ($y > 0$) and estimate the relationships between $\log y$ and the other variables of interests in a hybrid panel regression model. Based on a simplified version of our basic model (see Table 2, Chapter 3.5)[99], this paragraph illustrates in more detail how the hybrid model compares to the correlated random-effects model and to standard random-effects and fixed-effects models. For illustration purposes, the variables are listed with prefixes; in the xthybrid model, the W_ prefix denotes within-cluster effects; variables with the B_ prefix show between-cluster effects and the R_prefix identifies variables for which standard random-effects estimation is used to assess their effects. Coefficients with the D_ prefix represent differences between between- and within- cluster effects, as they result from the correlated random-effects model. The estimation for the hybrid and the correlated random-effects model are performed in an automated procedure using Stata's `xthybrid` command, estimating two separate effects only for the *FF subsidies* variable, according to the test of the random-effect assumption discussed above. All other variables do not vary (sufficiently) within clusters or – if they do so – do not have within-cluster effects that are significantly different from between-cluster effects.

The results from the hybrid model are presented in Table A 2, Column 1. The coefficient W__FF subsidies p.c. (log) denotes the within-cluster effects of *FF subsidies*. Increases of FF subsidies within a country are hence not associated with a decrease of renewables in the power mix in a statistically significant way. The coefficient B__ FF subsidies p.c. (log) (-0.117**) gives its between-cluster effect. It suggests that a 1 % increase in the time-average of fossil fuel subsidies per capita is associated with a 0.12 % decrease in the share of renewables in total electricity production.

The coefficients of all other variables are estimated in the same way as in a random-effects regression, as discussed above. However, since the hybrid model also includes the cluster-mean of fossil fuel subsidies, the coefficients with R_ prefix in the hybrid model are not identical with coefficients from a standard random-effects model (Column 3). The estimates with R_ prefix being unbiased still rests on the assumption that the random-effects (such as unobserved effects on the country level) are uncorrelated with the observed covariates. Using the `xthybrid` command, we can specify an analogous correlated random-effects model (CRE) by adding the `cre` option. Results are presented in Column 2.

[99] In the example presented for illustration purposes here, we separate within- and between-cluster effects only for the subsidy variable.

Table A 2 Comparison of coefficients from a hybrid model with other linear models

	(1) Hybrid model	(2) CRE model	(3) RE model	(4) FE model
W_FF Subsidies p.c. (log)	-0.005 (0.011)	-0.005 (0.011)		
B_FF Subsidies p.c. (log)	-0.117** (0.058)			
D_FF Subsidies p.c. (log)		-0.112* (0.058)		
R_OPEC	-1.878* (1.088)	-1.878* (1.088)		
R_RE policies	0.096** (0.044)	0.096** (0.044)		
R_RE potential	0.002** (0.001)	0.002** (0.001)		
R_GDP p.c. (log)	0.030 (0.253)	0.030 (0.253)		
R_Democracy	0.139*** (0.051)	0.139*** (0.051)		
R_Energy consumption (log)	-0.279** (0.127)	-0.279** (0.127)		
R_Environmental performance	0.054*** (0.015)	0.054*** (0.015)		
FF subsidies			-0.010 (0.012)	-0.005 (0.011)
RE policies			0.105** (0.045)	0.048 (0.044)
Environmental performance			0.057*** (0.015)	0.076*** (0.026)
Democracy			0.165*** (0.049)	0.092 (0.064)
RE potential			0.002** (0.001)	–
OPEC			-2.527*** (0.931)	–
GDP p.c. (log)			-0.123 (0.227)	2.829*** (0.495)
Energy consumption			-0.307*** (0.107)	-1.607*** (0.301)
Constant	7.338*** (2.065)	7.338*** (2.065)	8.636*** (1.806)	-19.890*** (4.986)
Observations	862	862	862	862
Number of countries	102	102	102	102
Year dummies	Yes	Yes	Yes	Yes

Standard errors in parentheses. *p < .1, ** p < .05, *** p < 0.01.

The coefficient W__FF subsidies p.c. (log) again denotes the within-cluster effects associated with FF subsidies and is identical to the one estimated in the hybrid model. The within-cluster effect of FF subsidies from both the hybrid and CRE models is the same as the one fit by a standard fixed-effects model (see Column 4) in this linear setting (does not hold for non-linear models). The coefficient D__ FF subsidies p.c. (log) (-0.112) represents the difference between the between- and the within- cluster effects, which can be seen when comparing the between- and within-cluster effects for the subsidy variable from the hybrid model (-0.117 - (-0.005) = -0.112). The coefficients of variables that do not or do hardly vary within countries (cluster-invariant), denoted with R_ prefix are identical to those in the hybrid model. To provide a comparison, Table A 2 also shows the estimates obtained with standard random-effects and fixed-effects models (estimated with `xtreg`) in Columns 3 and 4 respectively.

Appendix B Robustness checks for regression results in Chapter 3

B1 Binary response models

The following tables show the results from robustness checks for binary response regressions employed to model the likelihood that a country produces any renewable electricity at all.

Table A 3 Hybrid probit random-effects with lagged support-policy variables

	(1) Main t	(2) RE policies t-1	(3) RE policies t-2	(4) RE policies t-3
FF subsidies p.c.(log)	-0.011 (0.153)	0.028 (0.138)	0.050 (0.240)	0.014 (0.120)
FF subsidies p.c.(log)	0.174 (0.163)	0.219 (0.181)	0.412*** (0.148)	0.100 (0.089)
RE policies	-0.132 (0.358)			
$\overline{\text{RE policies}}$	5.572*** (0.598)			
Environmental performance	-0.150 (0.176)	-0.159 (0.184)	-0.079 (0.231)	-0.181 (0.190)
$\overline{\text{Environmental performance}}$	0.125** (0.053)	0.115*** (0.044)	0.175*** (0.059)	0.105*** (0.033)
Democracy	0.128 (0.182)	0.152 (0.199)	0.208 (0.265)	0.083 (0.105)
Re potential	0.028** (0.012)	0.026*** (0.010)	0.033*** (0.009)	0.014*** (0.005)
OPEC	-9.409*** (2.290)	-8.251*** (1.936)	-10.143*** (3.851)	-5.109*** (1.256)
GDP p.c.(log)	0.097 (0.469)	0.076 (0.530)	-0.043 (0.640)	0.272 (0.289)
RE policies_t-1		-0.134 (0.400)		
$\overline{\text{RE policies\_t-1}}$		5.691*** (0.737)		
RE policies_t-2			0.251 (0.765)	
$\overline{\text{RE policies\_t-2}}$			16.184*** (1.219)	
RE policies_t-3				0.995* (0.599)
$\overline{\text{RE policies\_t-3}}$				4.644*** (0.720)
Constant	-7.072 (4.335)	-11.680** (4.545)	-17.889*** (4.450)	-9.629*** (2.725)
Log Likelihood	-153.993	-142.793	-119.575	-111.880
Observations	1392	1284	1130	977
Number of countries	155	155	155	155
Year dummies	Yes	Yes	Yes	Yes

Standard errors in parentheses. *$p < .1$, ** $p < .05$, *** $p < 0.01$.

Table A 4 Hybrid probit random-effects – low-income and emerging countries

	(1)	(2)	(3)	(4)
FF subsidies p.c.(log)	-0.045	-0.042	-0.055	-0.066
	(0.190)	(0.195)	(0.173)	(0.167)
$\overline{\text{FF subsidies p.c.(log)}}$	0.140	-0.146	0.120	-0.450***
	(0.106)	(0.152)	(0.121)	(0.116)
RE policies	-0.245	-0.326	-0.283	-0.240
	(0.488)	(0.489)	(0.481)	(0.487)
$\overline{\text{RE policies}}$	6.318***	4.649***	6.306***	4.272***
	(0.665)	(1.052)	(0.686)	(0.806)
Environmental performance	-0.076	-0.052	-0.059	-0.043
	(0.190)	(0.226)	(0.189)	(0.166)
$\overline{\text{Environmental performance}}$	0.163***	0.196***	0.149**	0.108***
	(0.055)	(0.045)	(0.063)	(0.036)
Democracy	0.164	0.293	0.161	0.318*
	(0.151)	(0.186)	(0.173)	(0.164)
Re potential	0.024***	0.017	0.027***	0.008
	(0.009)	(0.012)	(0.009)	(0.007)
OPEC	-10.542***	-10.491***	-9.956***	
	(1.659)	(2.345)	(1.967)	
GDP p.c.(log)	0.418	-0.569	0.525	-0.324
	(0.498)	(0.891)	(0.544)	(0.466)
Energy consumption (log)		1.601***		1.850***
		(0.574)		(0.416)
Net energy imports share			0.002	
			(0.002)	
Constant	-11.000**	-2.365	-11.501**	-0.685
	(4.372)	(8.102)	(4.977)	(4.343)
Log Likelihood	-137.927	-135.059	-137.660	-139.183
Observations	1107	1107	1107	1107
Number of countries	124	124	124	124
Year Dummies	Yes	Yes	Yes	Yes

Standard errors in parentheses. *$p < .1$, ** $p < .05$, *** $p < 0.01$.

Table A 5 Pooled probit random-effects – country subsets with high subsidy variation

	(1) ffs_40	(2) ffs_50	(3) ffs_60	(4) ffs_70
FF subsidies p.c.(log)	-0.038	-0.032	0.004	0.033
	(0.044)	(0.033)	(0.063)	(0.076)
RE policies	0.587**	0.530**	0.412	0.358
	(0.259)	(0.263)	(0.356)	(0.409)
Environmental performance	0.033	0.037	0.019	0.015
	(0.021)	(0.023)	(0.024)	(0.025)
Democracy	0.173***	0.191***	0.284***	0.269***
	(0.062)	(0.069)	(0.087)	(0.096)
Re potential	0.009**	0.012***	0.003	0.003**
	(0.004)	(0.004)	(0.002)	(0.001)
OPEC	-1.427**	-1.329*	-0.866	-0.778
	(0.588)	(0.696)	(0.652)	(0.678)
GDP p.c.(log)	-0.025	0.126	-0.063	-0.133
	(0.293)	(0.300)	(0.265)	(0.285)
Constant	-1.909	-3.861	-1.123	-0.297
	(2.606)	(2.726)	(2.509)	(2.694)
Log Likelihood	-138.60	-117.11	-86.76	-70.90
Observations	430	357	260	197
Number of countries	49	41	31	23
Year dummies	Yes	Yes	Yes	Yes

Results are from pooled probit regressions. * $p < .1$, ** $p < .05$, *** $p < 0.01$.
Country-clustered standard errors in parentheses. FF stands for fossil fuels; RE for renewable energy. Model titles refer to thresholds for limiting the sample to those countries with the highest variation in subsidies (higher than the 40th, 50th, 60th and 70th percentile respectively).

B2 Linear panel regression models

The following tables show the results from robustness checks for linear regressions employed in the second part of the statistical model in Chapter 3.5.

Table A 6 Linear hybrid panel regression - low-income and emerging countries

	(1)	(2)	(3)	(4)
FF subsidies p.c.(log)	-0.003 (0.016)	-0.002 (0.016)	-0.003 (0.016)	0.015 (0.016)
$\overline{\text{FF subsidies p.c.(log)}}$	-0.173** (0.069)	-0.074 (0.075)	-0.166** (0.069)	-0.120* (0.070)
RE policies	0.143** (0.066)	0.143** (0.065)	0.130** (0.066)	0.198*** (0.070)
$\overline{\text{RE policies}}$	0.129 (0.296)	0.535* (0.324)	0.108 (0.308)	0.406 (0.308)
Environmental performance	0.050** (0.022)	0.045** (0.022)	0.052** (0.022)	0.044** (0.021)
Democracy	0.149** (0.061)	0.138** (0.060)	0.154** (0.061)	0.161** (0.065)
RE potential	0.001 (0.001)	0.004** (0.002)	0.001 (0.001)	0.001 (0.001)
OPEC	-1.305 (1.214)	-1.159 (1.215)	-1.276 (1.211)	-1.452 (1.158)
GDP p.c.(log)	-0.400 (0.303)	-0.066 (0.329)	-0.436 (0.307)	-0.411 (0.314)
Energy consumption (log)		-0.547*** (0.176)		
Net energy imports share			-0.002** (0.001)	
$\overline{\text{Net energy imports share}}$			0.000 (0.002)	
Hydro electricity share				-0.014* (0.007)
$\overline{\text{Hydro electricity share}}$				0.015 (0.010)
Nuclear electricity share				-0.040*** (0.008)
Constant	10.273*** (2.405)	6.706** (2.747)	10.522*** (2.421)	10.282*** (2.489)
Log Likelihood	-1208.22	-1195.82	-1207.85	-1083.48
Observations	584	584	584	538
Number of countries	71	71	71	64
Year dummies	Yes	Yes	Yes	Yes

Standard errors in parentheses. * $p < .1$, ** $p < .05$, *** $p < 0.01$. Log Likelihood for model comparison. FF stands for fossil fuels, RE for renewable energy.

Table A 7 Linear hybrid panel regression - countries with high subsidy variation

	(1) basic	(2) ffs_40	(3) ffs_50	(4) ffs_60	(5) ffs_70
FF subsidies p.c.(log)	-0.005	-0.051**	-0.061**	-0.118***	-0.120***
	(0.012)	(0.023)	(0.027)	(0.041)	(0.033)
$\overline{\text{FF subsidies p.c.(log)}}$	-0.162***	0.044	0.083	0.366***	0.369***
	(0.054)	(0.114)	(0.148)	(0.140)	(0.059)
RE policies	0.087*	0.307***	0.412***	0.384*	-0.060
	(0.045)	(0.119)	(0.146)	(0.203)	(0.188)
$\overline{\text{RE policies}}$	0.219	0.855**	0.705	0.717*	0.570***
	(0.231)	(0.415)	(0.447)	(0.392)	(0.216)
Environmental performance	0.055***	0.109***	0.122***	0.043	0.036**
	(0.015)	(0.028)	(0.034)	(0.030)	(0.015)
Democracy	0.134**	0.125	0.177*	0.479***	0.412***
	(0.052)	(0.088)	(0.106)	(0.136)	(0.057)
RE potential	0.001	0.004*	0.004*	0.005***	0.004***
	(0.001)	(0.002)	(0.002)	(0.002)	(0.001)
OPEC	-1.745	-1.810	-1.564	-0.417	-1.062***
	(1.077)	(1.162)	(1.209)	(0.785)	(0.305)
GDP p.c.(log)	-0.262	-1.407***	-1.924***	-1.499***	-2.362***
	(0.221)	(0.483)	(0.554)	(0.433)	(0.236)
Constant	8.862***	14.917***	18.764***	15.157***	24.362***
	(1.654)	(3.739)	(4.558)	(4.024)	(2.230)
Log Likelihood	-1725.75	-563.33	-445.59	-278.11	-129.62
Observations	862	284	219	151	100
Number of countries	102	34	27	19	13
Year Dummies	Yes	Yes	Yes	Yes	Yes

Standard errors in parentheses. *$p < .1$, ** $p < .05$, *** $p < 0.01$. Log Likelihood for model comparison. FF stands for fossil fuels, RE for renewable energy. Model titles refer to thresholds for limiting sample to those countries with the highest variation in subsidies (higher than the 40th, 50th, 60th and 70th percentile respectively).

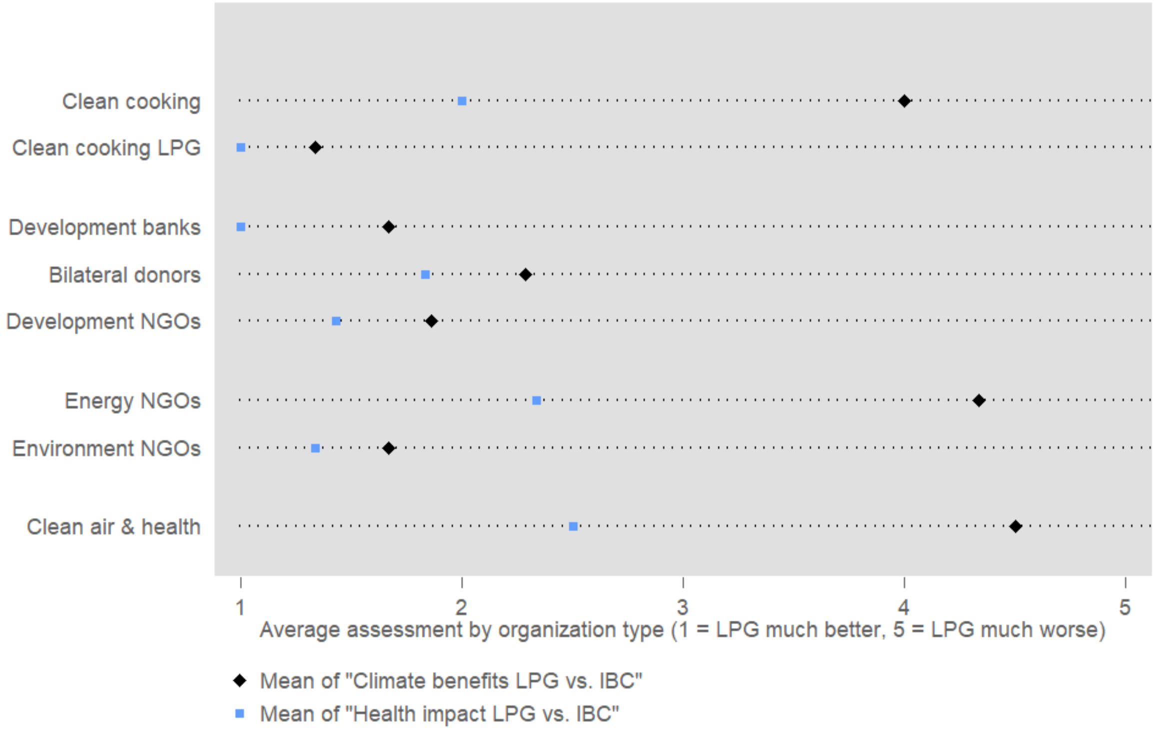
Table A 8 Linear fixed-effects panel regression – countries with high subsidy variation

	(1) basic	(2) ffs_40	(3) ffs_50	(4) ffs_60	(5) ffs_70
FF subsidies p.c.(log)	-0.008	-0.059*	-0.070*	-0.108**	-0.120***
	(0.020)	(0.030)	(0.035)	(0.038)	(0.033)
RE policies	0.052	0.275	0.407	0.298	-0.097
	(0.087)	(0.260)	(0.322)	(0.349)	(0.219)
Environmental performance	0.106**	0.167**	0.197**	0.123	0.115
	(0.048)	(0.071)	(0.077)	(0.112)	(0.090)
Democracy	0.055	0.024	0.098	0.794	0.490
	(0.067)	(0.098)	(0.129)	(0.718)	(0.577)
GDP p.c.(log)	1.516**	2.995**	3.307	3.318	3.419
	(0.726)	(1.377)	(2.363)	(2.992)	(3.476)
Constant	-9.153	-27.709*	-32.807	-33.952	-33.394
	(7.975)	(14.291)	(23.375)	(29.249)	(36.153)
Observations	862	284	219	151	100
Number of countries	102	34	27	19	13
Year Dummies	Yes	Yes	Yes	Yes	Yes

Country-clustered standard errors in parentheses. * $p < .1$, ** $p < .05$, *** $p < 0.01$. FF stands for fossil fuels; RE for renewable energy. Model titles refer to thresholds for limiting sample to those countries with the highest variation in subsidies (higher than the 40th, 50th, 60th and 70th percentile respectively).

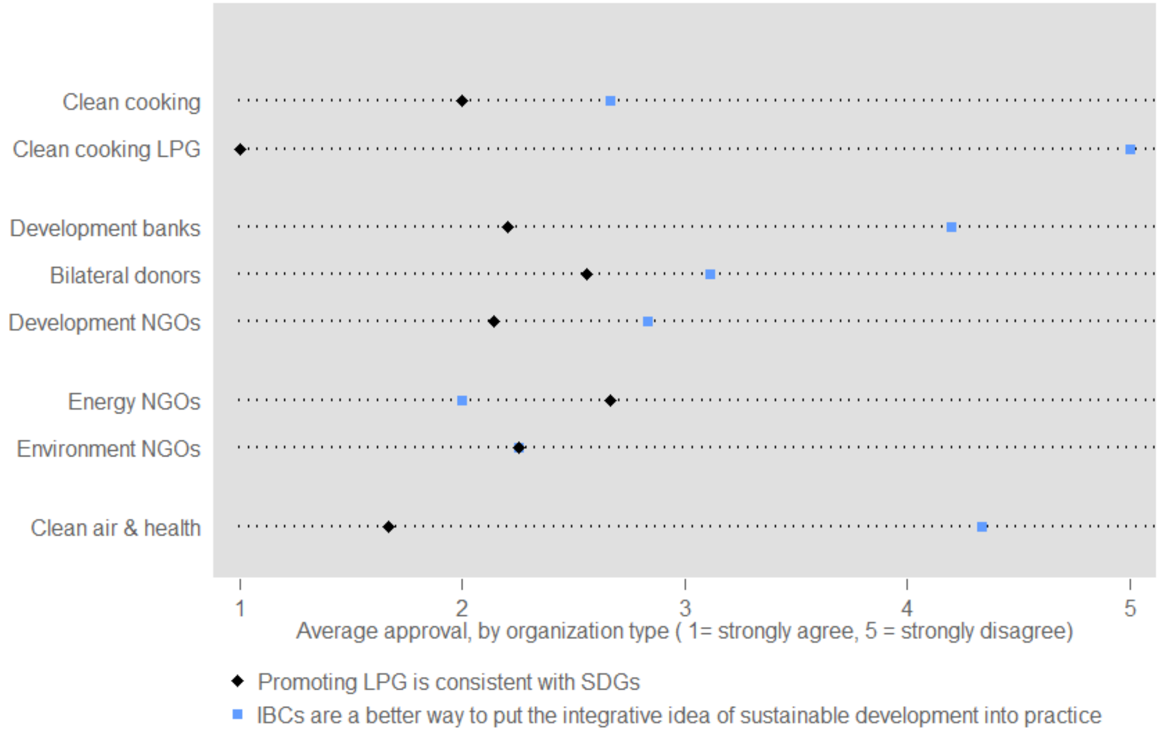
Appendix C Further results from online survey on LPG interventions

Figure A 1 Assessment of climate- and health benefits of LPG vs. IBC



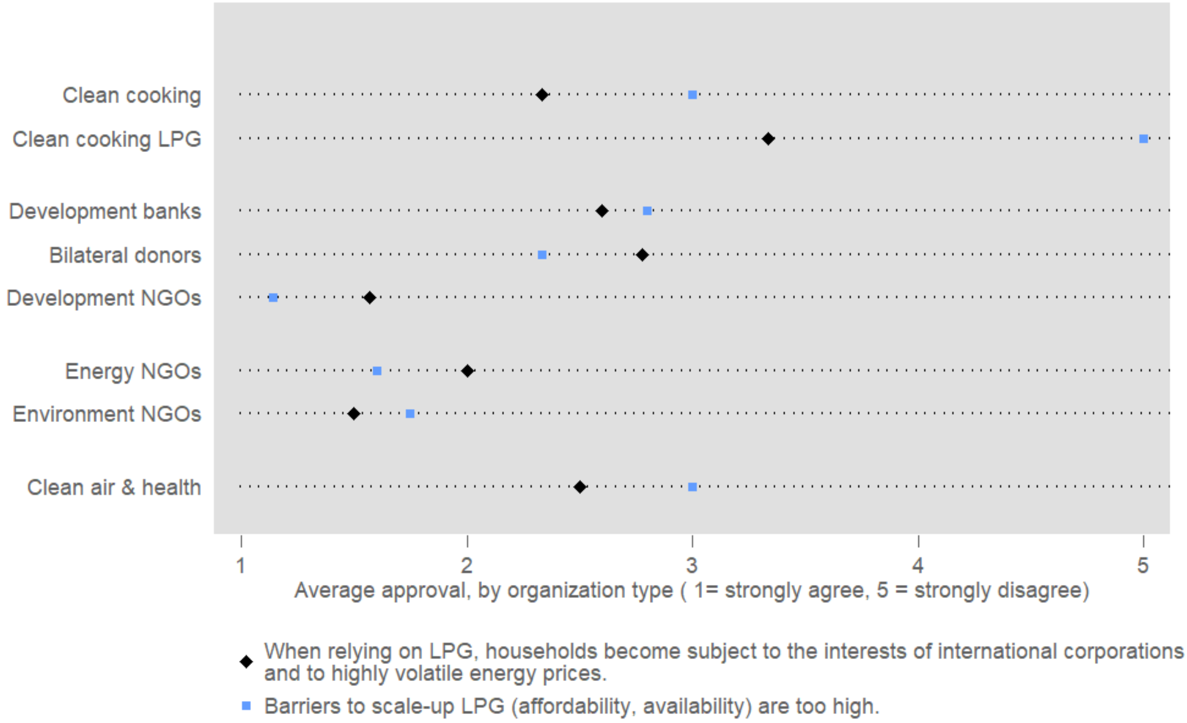
Note: Respondent's assessment of scientific evidence on the climate- and health benefits of switching from traditional cooking to LPG as compared to improved biomass stoves. For the comparison, respondents were asked to refer to the real-life effectiveness of these options as a replacement for traditional biomass cookstoves and the type of improved solid fuel stove most commonly promoted by their organization. 'Clean cooking' stands for clean cooking platform initiatives such as clean cooking alliances, whereas the answers from the Global LPG Partnership ('Clean cooking LPG') are shown separately for more accuracy. 'NGO energy' stands for NGOs, think-thanks or social businesses that are specialized on energy and sustainable development (with an energy focus).

Figure A 2 Views on LPG vs. IBCs in the context of sustainable development



Note: 'Clean cooking' stands for clean cooking platform initiatives such as clean cooking alliances, whereas the answers from the Global LPG Partnership ('Clean cooking LPG') are shown separately for more accuracy. 'NGO energy' stands for NGOs, think-thanks or social businesses that are specialized on energy and sustainable development (with an energy focus).

Figure A 3 Views on price dependence and on barriers for LPG scale-up



Note: 'Clean cooking' stands for clean cooking platform initiatives such as clean cooking alliances, whereas the answers from the Global LPG Partnership ('Clean cooking LPG') are shown separately for more accuracy. 'NGO energy' stands for NGOs, think-thanks or social businesses that are specialized on energy and sustainable development (with an energy focus).

Appendix D Methodological approach online survey and personal interviews

D1 Sampling and survey implementation

To collect detailed information on the role of LPG and attitudes towards its promotion in the clean cooking sector, I conducted an online survey among experts in key organizations engaged in the field. To that aim, I proceeded as follows:

In order to obtain the most representative sample possible, I first identified the types of organizations and policy areas relevant to the sector. For each type, I contacted several important organizations, whereby I sought to capture as well as possible the involved actors' diversity concerning their approaches to the issue – such as general development and poverty reduction, health or environment- and climate protection – but also concerning geography.

This exercise resulted in a sample of 73 organizations to be contacted. It includes, amongst others, the 20 bilateral donor countries with the highest ODA amounts within the OECD DAC, all major development banks, a key multi-donor program and several international organizations and initiatives, a wide range of development- and environment non-governmental organizations and large private foundations and, finally, representatives from the industry (LPG and efficient cookstove producers). The selection of relevant multilateral organizations and initiatives is straightforward and based on the volume of their activities in the sector. With regard to INGOs and NGOs, I have used cookstove project registries and the list of organizations with observer status at the UNFCCC to identify organizations engaged in the sector and searched the websites of major international aid organizations to check whether they have been running cookstove projects.

The survey was conducted from March until August 2019 through a standardized online questionnaire that was sent to senior or high-level officials in the corresponding department of each organization in the sample. If the first request remained unanswered, two reminders were sent after one and two weeks respectively. Contacting the experts via several initial connections and writing to them personally resulted in a high response rate, as 37 organizations completed the survey. In addition, the Climate & Clean Air Coalition circulated the survey within its global network of experts and professionals in the sector. In total, 48 answers from 43 organizations were obtained through the structured online survey (46) and two phone interviews (2). Table A 9 summarizes the number of responses by organization type.

Table A 9 Survey responses, by type of organization

Organization type	No. of directly contacted organizations	No. of responses (number of organizations)
Bilateral Donors & EU institutions	21	9 +2 phone interviews
Development Banks	5	5 (4)
UN-Organizations & Multi-donor program	3	1
Clean cooking organizations (international & national)	4	5 (3)
International public health- / clean air organizations	4	3
Development NGOs & foundations	19	9 (8)
Environment / energy / sustainable development NGOs and social businesses:	11	11(10)
Industry	4	1
Further (research)	1	2
Total	72	48

The organizations that participated in the survey essentially mirror the full range of activities in the clean cooking sector, including planning, implementing and evaluating projects to promote access to clean cooking alternatives, producing the appliances, providing financial and analytical support, assuming coordination and advocacy functions, and monitoring the achievement of objectives. Regarding the diversity of interests and policy areas, the representativeness of the survey is limited as far as the private sector is concerned: Despite several attempts, no response could be obtained from an efficient biomass cookstove producer (while I obtained one from a representative from the LPG industry). To avoid any bias and because industry and research do not directly influence the design of programmes, I decided not to include the answers from these areas in the statistical analysis of the online survey. Furthermore, no private foundations responded to the survey. Nevertheless, among all other types of organizations, the diversity of interests and policy areas is appropriately represented.

In particular, among the non-governmental organizations, there are general aid organizations, international climate and environmental organizations and some smaller, national organizations, some of which have a strong focus on sustainable development and renewable energy and do policy advice.

Some respondents preferred not to be cited by their names and among those, some wished that their organization should not be disclosed either. Aiming to balance this need for confidentiality with the need to provide the reader the information she or he requires to assess my ability to defend my claims, I produced two tables. Table A 10 lists all participating organizations of the online survey and those who were part of the sample frame but did not participate. The table contains information on the status and date of participation and on the position of the contributing expert. I have omitted all names and chose job titles which are general enough to disguise the identities of some interviewees. Table A 11 lists all personal interviews. Most interviews were audio-recorded and transcribed, yet in a few cases, I worked with notes. Before publication, direct quotations were submitted to the interview partners for approval and adapted as necessary.

The online survey contained predominantly closed-ended and a few open-ended questions. The questionnaire is provided below. The topics covered in personal interviews varied substantially depending on who was interviewed, but the overarching focus always revolved around the ongoing development of the clean cooking sector, views on the (changing) role of LPG and the arguments underpinning these views.

Table A 10 Sample frame and list of organizations participating in online survey

	Organization	Function	Status	Source	Format	Transcript
			Bilateral Donors			
S1	Belgium Belgian Development Agency (Enabel)	Senior Environment & Climate Advisor	Response 04/24/2019	Sample frame	Structured online survey	not applicable (n/a)
S2	Anonymous European donor Ministry of Foreign Affairs	Head of Section multilateral co-operation and climate change	Response 06/07/2019	Sample frame	Structured online survey	n/a
S3	Norway Norwegian Agency for Development Cooperation (Norad)	Senior Adviser, Department for Climate, Energy and Environment	Response 05/16/2019	Sample frame	Online Survey filled based on semi-structured phone interview	n/a
S4	United States U.S. Agency for International Development (USAID)	Senior Science Advisor, Bureau of Global Health	Response 04/08/2019	Sample frame	Structured online survey	n/a
S5	United Kingdom Department for International Development (DFID)	Senior Energy Adviser	No response	Sample frame	n/a	n/a
S6	Anonymous European donor Department of Foreign Affairs	Senior Development Specialist	Response 04/25/2019	Sample frame	Structured online survey	n/a
S7	Anonymous European donor Ministry of Foreign Affairs	Senior Policy Officer Climate and Renewable Energy	Response 04/25/2019	Sample frame	Structured online survey	n/a
S8	Germany German Federal Ministry for Economic Cooperation and Development (BMZ)	Division Energy, Infrastructure, Raw Materials	Response 22/03/2019	Sample frame	Open-question phone-interview	Notes, confi-dentiality required

Table A 10 continued

	Organization	Function	Status	Source	Format	Transcript
S9	Japan International Cooperation Agency (JICA)	Energy and Mining Group, Industrial Development and Public Policy Dept.	Response 25/04/2019	Sample frame	Open-question phone-interview	Notes, confi-dentiality required
S10	Anonymous European donor Development agency	Climate Change and Environment Program	Response 03/20/2019	Sample frame	Structured online survey	n/a
S11	Anonymous European donor Development agency	Climate change portfolio SSA	Response 03/19/2019	Sample frame	Structured online survey	n/a
S12	Anonymous European donor Ministry for Foreign Affairs	Desk Officer	Response 04/18/2019	Sample frame	Structured online survey	n/a
S13	EU Institutions	DEVCO - C6, Sustainable Energy, Climate Change	No response	Sample frame	n/a	n/a
S14	France Agence Française de Développement (AFD)	Energy Division	No response	Sample frame	n/a	n/a
S15	South Korea Korea International Cooperation Agency	Climate Change and Environment Department	No response	Sample frame	n/a	n/a
S16	Austria Austrian Development Agency (ADA)	Advisor on Energy	No response	Sample frame	n/a	n/a
S17	Australia Australian Agency for International Development (Australian Aid)	Request via contact form	No response	Sample frame	n/a	n/a
S18	Canada Global Affairs Canada	Request via contact form & contact person outside organization	No response	Sample frame	n/a	n/a

Table A 10 continued

	Organization	Function	Status	Source	Format	Transcript
S19	Italy Italian Agency for Development Cooperation (AICS) HQ	Request via contact form	No response	Sample frame	n/a	n/a
S20	Spain Spanish Agency for International Development Cooperation (AECID)	Request via contact form	No response	Sample frame	n/a	n/a
S21	Poland Ministry of Foreign Affairs, Department of Development Cooperation (Polish aid)	Request via contact form & contact person outside organization	No response	Sample frame	n/a	n/a
	Development Banks					
S22	Inter-American Development Bank Climate Change and Sustainability Division	Climate change specialist	Response 06/12/2019	Sample frame	Structured online survey	n/a
S23	The World Bank Energy Sector Management Assistance Program (ESMAP)	Senior energy specialist, efficient and clean cooking and heating program	Response 03/22/2019	Sample frame		n/a
S24	Anonymous regional development bank	Senior Investment Officer, renewable energy and clean cooking	Response 04/18/2019	Sample frame	Structured online survey	n/a
S25	Kreditanstalt für Wiederaufbau KfW (German development bank)	Management Department Southern Africa and Regional Funds	Response 05/22/2019	Sample frame	Structured online survey	n/a
S26	KfW	Competence Centre Climate and Energy	Response 04/02/2019	Sample frame	Structured online survey	n/a

Table A 10 continued

	Organization	Function	Status	Source	Format	Transcript
S27	Asian Development Bank	Specialists at Energy for All Initiative, Sustainable Infrastructure Division, Southeast Asia Energy Division	No response	Sample frame	n/a	n/a
		UN Organizations & Multi-donor program				
S28	Sustainable Energy for All (SEforALL)	Senior Advisor	No response	Sample frame	n/a	n/a
S29	UNDP	Management Energy, Infrastructure, Transport and Technology	No response	Sample frame	n/a	n/a
S30	Energising Development (EnDev), Multi-donor Program	Senior energy advisor, Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ)	Response 04/03/2019	Sample frame	Structured online survey	n/a
		Clean cooking organizations (platform initiatives)				
S31	Global LPG Partnership	Director of Research, Monitoring and Evaluation	Response 03/28/2019	Sample frame	Structured online survey	n/a
S32		Program Manager, Energy and Microfinance	Response 03/28/2019	CCAC email circulation	Structured online survey	n/a
S33		Country Manager, Kenya	Response 03/27/2019	CCAC email circulation	Structured online survey	n/a
S34	Anonymous transnational organization promoting clean and improved cookstoves	Program Manager for Fuels	Response 03/26/2019	Sample frame	Structured online survey	n/a

Table A 10 continued

	Organization	Function	Status	Source	Format	Transcript
S35		Senior Manager, Technology & Impacts	No response	Sample frame	n/a	n/a
S36	Anonymous national cookstove association in Africa	Component Leader	Response 07/22/2019	CCAC email circulation	Structured online survey	n/a
S37	Côte d'Ivoire Alliance for Clean Cooking (CIACC)	Management	Response 03/22/2019	CCAC email circulation	Structured online survey	n/a
S38	Clean Cookstoves Association of Kenya	Manager, Practical Action Consulting	No response	Sample frame	n/a	n/a
S39	Uganda National Alliance on Clean Cooking (UNACC)	Coordinator	No response	Sample frame	n/a	n/a
	International public health- / clean air organizations					
S40	World Health Organization	Team Leader on Household Energy and Health	Response 04/09/2019	Sample frame	Structured online survey	n/a
S41	Climate and Clean Air Coalition	Finance & Household Energy Initiative Coordinator	Response 03/28/2019	Sample frame	Structured online survey	n/a
S42	Pan American Health Organization	Consultant	Response 03/28/2019	Sample frame	Structured online survey	n/a
S43	Clean Air Asia	Senior Air Quality Program Coordinator	No response	Sample frame	Structured online survey	n/a
	Development NGOs & Foundations					
S44	Practical Action	Energy Access Partnership and Innovation Manager	Response 03/21/2019	Sample frame	Structured online survey	n/a

Table A 10 continued

	Organization	Function	Status	Source	Format	Transcript
S45	Major global aid organization	Manager Food Security and Natural Resources	Response 08/07/2019	Sample frame	Structured online survey	n/a
S46	ActionAid	Program Manager	Response 04/04/2019	Sample frame	Structured online survey	n/a
S47	Christian Aid UK	Christian Aid Nigeria Country Manager	Response 03/27/2019	Sample frame	Structured online survey	n/a
S48	The Cookstove Project	Management	Response 03/28/2019	Sample frame	Structured online survey	n/a
S49	Project Gaia	Director and Household Energy Specialist	Response 03/31/2019	Sample frame	Structured online survey	n/a
S50	For Stoves	Management	No response	Sample frame	n/a	n/a
S51	Anonymous major Swiss aid organization	Program Director	Response 03/27/2019	Sample frame	Structured online survey	n/a
S52		Senior Advisor Energy and Climate Change	Response 03/26/2019	Sample frame	Structured online survey	n/a
S53	Fastenopfer	Country Program Kenya	Response 03/25/2019	Sample frame	Structured online survey	n/a
S54	SNV Foundation Netherlands	Coordinator Sustainable Energy Markets	No response	Sample frame	n/a	n/a
S55	Catholic Agency For Overseas Development (CAFOD)	Analyst Climate Change and Energy	No response	Sample frame	n/a	n/a
S56	Entrepreneurs du monde	Energy programs	No response	Sample frame	n/a	n/a
S57	AidAfrica	Request via contact form	No response	Sample frame	n/a	n/a

Table A 10 continued

	Organization	Function	Status	Source	Format	Transcript
S58	Rural Services Foundation	Request via contact form	No response	Sample frame	n/a	n/a
S59	Initiative Développement	Request via contact form	No response	Sample frame	n/a	n/a
S60	Asian Fund for Relief and Development (AFRD)	Request via contact form	No response	Sample frame	n/a	n/a
S61	Amom Foundation	Management Operations and Development	No response	Sample frame	n/a	n/a
S62	Bright Generation Community Foundation	Management	No response	Sample frame	n/a	n/a
S63	Bill and Melinda Gates Foundation	Request via contact form	No response	Sample frame	n/a	n/a
	Environment and energy NGOs and social businesses					
	Environment					
S64	WWF Switzerland	Project leader	Response 05/28/2019	Sample frame	Structured online survey	n/a
S65		Senior Manager Climate and Energy	Response 05/28/2019	Sample frame	Structured online survey	n/a
S66	GreenWorks Consulting	Senior Executive	Response 03/29/2019	Sample frame	Structured online survey	n/a
S67	Anonymous non-profit foundation in the area of carbon off-setting	Technical Director	Response 07/31/2019	Sample frame	Structured online survey	n/a
S68	FairClimateFund	Management	Response 07/25/2019	Sample frame	Structured online survey	n/a

Table A 10 continued

	Organization	Function	Status	Source	Format	Transcript
	Energy & sustainable development					
S69	SWITCH-Asia	Team Leader	No response	Sample frame	n/a	n/a
S70	TERI – The Energy and Resources Institute	Associate Fellow	Response 03/28/2019	Sample frame	Structured online survey	n/a
S71	Loja de Energias	Founder	Response 03/22/2019	CCAC email circulation	Structured online survey	n/a
S72	Microsol	Management	Response 04/01/2019	Sample frame	Structured online survey	n/a
S73	GERES	Director Expertise and Strategic Advice	Response 06/24/2019	Sample frame	Structured online survey	n/a
S74	Zambia Energy and Environmental Organization (ZENGO)	Collaborator	Response 03/22/2019	CCAC email circulation	Structured online survey	n/a
S75	Energy 4 Impact	Management and Program Manager	No response	Sample frame	n/a	n/a
S76	CARE India Solutions for Sustainable Development	Request to headquarters	No response	Sample frame	n/a	n/a
			Industry			
S77	World LPG Association	Management, Market Development	Response 04/02/2019	Sample frame	Structured online survey	n/a
S78	Envirofit	Communications and Public Relations	No response	Sample frame	n/a	n/a
S79	Envirofit India	Management	No response	Sample frame	n/a	n/a

Table A 10 continued

	Organization	Function	Status	Source	Format	Transcript
S80	EcoZoom Stoves	Global Sales & Marketing	No response	Sample frame	n/a	n/a
			Research and others			
S81	Research Team KfW commissioned research	Several Professors in public health	No response	Sample frame	n/a	n/a
S82	Clean Cooking Implementation Science Network (ISN) / Fogarty International Center, U.S. National Institutes of Health	Principal Scientist	Response 04/23/2019	CCAC email circulation	Structured online survey	n/a
S83	Africa Interdisciplinary Centre for Climate-Smart Agriculture Adaptation and Resilience (AICCAAR)	CEO	Response 08/21/ 2019	CCAC email circulation	Structured online survey	n/a

Table A 11 List of personal interviews

No.	Organization	Function	Status	Format	Duration	Recording	Transcript
P1	World Bank Group Energy Sector Management Assistance Program (ESMAP)	Senior Energy Specialist, Senior Official Efficient and Clean Cooking and Heating Program	Telephone interview via Skype 03/22/2019	Semi-structured	61 min	Audio recording	Confidentiality required
P2	Inter-American Development Bank Climate Change and Sustainability Division	Lead climate change specialist	Telephone interview via Skype 07/02/2019	Semi-structured	25 min	Audio recording	Confidentiality required
P3	The Global LPG Partnership	Senior Official, Research, Monitoring & Evaluation	Telephone interviews via Skype on 04/05/2019 and 05/03/2019	Semi-structured	28 min 69 min	Audio recording	Confidentiality required
P4	Norwegian Agency for Development Cooperation (NORAD)	Senior Adviser, Dep. for Climate, Energy and Environment	Telephone interview 05/16/2019	Online Survey filled based on semi-structured phone interview	Appr. 45 min	Concurrent notes and supplementary notes w/i 1 hr	Confidentiality required
P5	Microsol (social business, development, coordination etc. of cookstove projects)	Management	Telephone interview via Skype 05/15/2019	Semi-structured	58 min	Audio recording	Confidentiality required

Table A 11 continued

P6	German development bank = Kreditanstalt für Wiederaufbau (KfW),	Senior Official, Department Southern Africa and Regional Funds	Telephone interview via Skype 05/23/2019	Semi-structured	51 min	Audio recording	Confidentiality required
P7	Inter-American Development Bank	Climate Change Senior Specialist	Telephone interview via Skype 10/11/2019	Semi-structured	38 min	Audio recording	Confidentiality required
P8	The Gold Standard Foundation	Senior Official, Standard Development Technical Director of Climate and Sustainability	Telephone interview via Skype 12/26/2019	Semi-structured	44 min	Audio recording	Confidentiality required
P9	Independent consultant	Expert on Climate Finance under the Paris Agreement, Proposal Evaluation and Development	Personal interview	Semi-structured	75 min	Concurrent notes and supplementary notes w/i 1 hr	Confidentiality required

D2 Questionnaire of online survey about LPG among experts in the clean cooking sector

Q1 Welcome and thank you for taking a moment!
To start with, please enter your contact details
Full Name ____
Email address ____
Phone number (optional) ______________________________

Q2 What is the name of your organization?__________________

Q3 The role of LPG in your organization
Your organization (directly or through partnerships) engages in programmes that aim to improve access to clean household fuels and technologies such as improved/advanced biomass cookstoves, biogas or LPG. How important are LPG programs for your organization, as compared to programs promoting other fuels and technologies?

- □ Unimportant
- □ Of little Importance
- □ Moderately important
- □ Important
- □ Very important

Q4 Can you estimate which share of funding in the area of clean-cooking is spent for LPG in your organization? (Informed guess is ok).
Share in % ____

Q5 Changes in LPG resources
Has there been any change in the relative amount of resources that your organization has been allocating to LPG promotion ?
Please refer to activities over the past 5 years, including those that are currently planned. Project implementation may be directly or through partnerships.

- □ Great decrease
- □ Slight decrease
- □ No change
- □ Slight increase
- □ Great increase

Q6 Are there any plans to change the relative share of resources allocated to LPG promotion in the future?

- □ Great decrease
- □ Slight decrease
- □ No change
- □ Slight increase
- □ Great increase

Q7 Scientific evidence on health impacts

How do you judge the scientific knowledge regarding the health benefits of LPG as compared to improved solid fuel stoves?
Please refer to the real-life effectiveness of these options, as a replacement of traditional biomass cookstoves and the type of improved solid fuel stove most commonly promoted by your organization.

- □ Much better
- □ Somewhat better
- □ About the same
- □ Somewhat worse
- □ Much worse
- □ Don’t know

Q8 Scientific evidence on climate impacts

How do you judge the scientific knowledge regarding the climate benefits of LPG as compared to improved solid fuel stoves?
Please refer to the real-life effectiveness of these options, as a replacement of traditional biomass cookstoves and the type of improved solid fuel stove most commonly promoted by your organization.

- □ Much better
- □ Somewhat better
- □ About the same
- □ Somewhat worse
- □ Much worse
- □ Don't know

Q9 Views regarding the focus of clean household energy programs

Some argue that instead of a continued focus on improved/advanced biomass cookstoves there should be increased efforts to promote the adoption and use of LPG. Do you agree?

- □ Strongly agree
- □ Somewhat agree
- □ Neither agree nor disagree
- □ Somewhat disagree
- □ Strongly disagree

Q10 Pros and cons of LPG vs. improved solid fuel stoves as clean cooking solutions (1/3)

Below you find a list of arguments that have been put forward in favour of efforts to promote either LPG or improved solid fuel stoves. Please indicate for each statement whether it corresponds to your opinion.

	Strongly agree	Somewhat agree	Neither agree nor disagree	Somewhat disagree	Strongly disagree
LPG corresponds better to household preferences than improved solid fuel stoves.	□	□	□	□	□
Promoting LPG is consistent with the Sustainable Development Goals.	□	□	□	□	□
Major time savings when cooking with LPG allow for higher social benefits, in particular for women.	□	□	□	□	□
Improved solid fuel stoves will not be sufficient to substantially reduce the health risks from household air pollution.	□	□	□	□	□

Q11 Pros and cons of LPG and improved solid fuel stoves as clean cooking solutions (2/3)

	Strongly agree	Somewhat agree	Neither agree nor disagree	Somewhat disagree	Strongly disagree
LPG can be seen as a transition fuel for clean household energy before biogas/solar/electricity is available everywhere.	☐	☐	☐	☐	☐
Barriers to scale-up LPG (affordability, availability) are too high.	☐	☐	☐	☐	☐
Improved solid fuel stoves are a better way to put the integrative idea of sustainable development into practice.	☐	☐	☐	☐	☐
LPG should not be promoted because it is a fossil fuel.	☐	☐	☐	☐	☐

Q12 Pros and cons of LPG and improved solid fuel stoves as clean cooking solutions (3/3)

	Strongly agree	Somewhat agree	Neither agree nor disagree	Somewhat disagree	Strongly disagree
Improved solid fuel stoves are a better way of promoting the local economy.	☐	☐	☐	☐	☐
When relying on LPG, households become subject to the interests of international corporations and to highly volatile energy prices.	☐	☐	☐	☐	☐
My organization obtains significant funding from donors that prefer to support improved solid fuel stoves rather than LPG.	☐	☐	☐	☐	☐

Q13 Could you specify the donors that wish to focus on funding improved biomass stoves?____

Q14 If you wish you can add further arguments here:

____

Q15 If you wish you can comment on any of the above arguments here:

____

Q16 Are decision makers in your organization likely to support a clean household energy strategy that will focus more strongly on promoting LPG?

- ☐ Definitely yes
- ☐ Probably yes
- ☐ Might or might not
- ☐ Probably not
- ☐ Definitely not

Q17 Are there any further comments you would like to share on the issues raised in this survey?

____

Q18 Please indicate whether you wish to remain anonymous

- ☐ You can cite me by name as long as I obtain the opportunity to check the quotes before publication.
- ☐ I wish to remain anonymous in any report on the results of this research.

Q19 Do you mind if I mention your organization?

- ☐ You can mention my organization
- ☐ I want my organization to remain undisclosed.

Q20 Would you be willing to answer further questions at a later time in a personal interview?

- ☐ Yes
- ☐ No

Appendix E Mathematical derivations for the theoretical model on LPG use

In this paper, we proposed an illustrative model based on the Cobb-Douglas utility function:

$$U(g, x) = g^{\theta} x^{1-\theta} \tag{1}$$

where g is the cooking gas LPG, x is a composite good that includes traditional biomass and other goods, and $\theta \in [0, 1]$ is an indicator for the preference for LPG as compared to the composite good.
For an income B and prices p_g and p_x, the budget constraint is:

$$g p_g + x p_x \leq B \tag{2}$$

Maximizing (1) subject to (2) yields the Marshallian demand function for LPG:

$$g^*(p_g) = \frac{B}{p_g} \cdot \theta \tag{3}$$

Inverting this function, we obtain the price a household is willing to pay for this quantity of LPG:

$$p_g(g^*) = \frac{B}{g^*} \cdot \theta. \tag{4}$$

Predictions related to WTP

Imagine we request the household to increase its consumption from g^* to $\bar{g} = 2g^*$ as we are interested in WTP for regular rather than very sporadic users. Assume that such a doubling of LPG consumption is feasible within the budget constraint (Assumption 1, see section 'Assumptions'). To make this situation again optimal for the household, the new price must be 50 % lower than the initial price:

$$p_g(\bar{g}) = \frac{B}{\bar{g}} \cdot \theta = \frac{1}{2} \cdot p_g(g^*) \tag{5}$$

While this exact relationship is directly related to the restrictive assumption underlying the Cobb-Douglas utility function that the price-elasticity of demand is equal to 1, even otherwise, we would clearly expect a reduction in WTP with an increase in the requested amount to be consumed. More interesting in the context of our study, however, is the question to what extent health messaging can compensate some of this reduction in WTP. What is the change in WTP if we increase the decision maker's knowledge about the adverse health effects of cooking with traditional biomass? Let us consider the preference for LPG θ as a linear function of health knowledge $h \in [0,1]$:

$$\theta = \bar{\theta} + h \cdot \gamma \tag{6}$$

where $\theta \in [0,1]$ is basic preference (e.g., due to the convenience and time savings associated with LPG) and $\gamma \in [0,1]$ is a factor reflecting the salience of health information, notably due to gender.

We can then rewrite $p_g(\bar{g})$ as:

$$p_g(\bar{g}) = \frac{B}{\bar{g}} \cdot (\bar{\theta} + h \cdot \gamma) \tag{7}$$

The expected effect of health messaging on WTP is then given by:

$$\frac{\partial p_g}{\partial h} = \frac{B}{\bar{g}} \cdot \gamma > 0 \tag{8}$$

We are further interested to see if the impact of health messaging is affected by differences related to gender reflected by differences in the salience of the health information. To see this, we need to take the cross-derivative with respect to h and γ. To do so, note that factors such as gender already influence the initial value of g^* and thus also $\bar{g}$. More formally, we can write:

$$\bar{g} = 2g^*\left(p_m, \bar{\bar{\theta}}\right) = 2\frac{B}{p_m} \cdot (\bar{\theta} + \bar{h} \cdot \gamma) \tag{9}$$

where p_m is the original market price and $\bar{\bar{\theta}} = \bar{\theta} + \bar{h} \cdot \gamma$ the initial preference for LPG. In other words, $\bar{g}$ is fixed as the double of the optimal consumption at the general market price and the initial preference for LPG$\bar{\bar{\theta}}$ that is based on the initial health knowledge and salience. We keep h fixed at this initial level $\bar{h}$ as its change due to the treatment does not influence g^*. In contrast, a greater salience of such health knowledge γ already influences the initial g^*. Hence, $\bar{g}$ needs to be considered as a function of γ but not of h when we take the derivatives. We assume that the treatment itself does not affect γ (see Assumption 2 below) which is obvious if we think of it as reflecting the gender of the decision maker. Inserting (9) in (8) and taking the derivative with respect to γ, we obtain:

$$\frac{\partial^2 p_g}{\partial h \partial \gamma} = \frac{\bar{\theta} p_m}{2\left(\bar{\theta} + \bar{h}\gamma\right)^2} > 0 \tag{10}$$

Predictions related to the propensity of voucher use

The propensity to use the voucher can be expressed as the difference in utility ΔU between a situation in which the voucher is used U_1 and a situation in which it is not used U_0. Taking into account the conditions for voucher use, namely doubling initial consumption and the discounted offer price p_d, we can specify U_1 as

$$U_1 = \bar{g}^{\theta} x^{1-\theta} = \bar{g}^{\theta} (B - \bar{g} p_d)^{1-\theta} \tag{11}$$

In contrast, the utility when the voucher is not used U_0 simply corresponds to Equation (1) evaluated at the optimal level of consumption given the market price p_m, without any discount but with the possibility to freely adjust all quantities to changes in θ:

$$U_0 = g^{*\theta} x^{*1-\theta} \tag{12}$$

ΔU can thus be rewritten as

$$\Delta U = U_1 - U_0 = \bar{g}^{\theta}(B - \bar{g}p_d)^{1-\theta} - g^{*\theta} x^{*1-\theta} \tag{13}$$

To facilitate the computation of the derivatives we simplify Equation (13) through a monotonous transformation using logs. This transformation will leave the sign of the derivatives unchanged.

$$\begin{aligned} \Delta u &= lnU_1 - lnU_0 \\ &= (1-\theta)ln\frac{B - 2g^*(p_m,\bar{\bar{\theta}})p_d}{B - g^*(p_m,\theta)p_m} + \theta ln\frac{2g^*(p_m,\bar{\bar{\theta}})}{g^*(p_m,\theta)} \\ &= (1-\theta)\ln\left(1 - 2\bar{\bar{\theta}}\frac{p_d}{p_m}\right) - (1-\theta)\ln(1-\theta) + \theta\ln(2\bar{\bar{\theta}}) - \theta ln\theta \end{aligned} \tag{14}$$

Replacing θ by (6) and taking the derivative with respect to h yields:

$$\frac{\partial \Delta u}{\partial h} = -\gamma \ln\left(\frac{1-2\bar{\bar{\theta}}\frac{p_d}{p_m}}{2\bar{\bar{\theta}}}\right) + \gamma \ln\left(\frac{1-\theta}{\theta}\right) > 0 \tag{15}$$

Note that this computation is again based on Assumption 1 (a doubling of consumption is feasible within the budget constraint), or else, we would take the log of a negative quantity in the first term. A further relevant assumption is that the requirement to double LPG consumption in order to use the voucher is a binding constraint (see Assumption 3 below). For more extreme preferences for LPG, the model would suggest that the household would forego the voucher in order to be able to consume more LPG. This situation is irrelevant in practice, as the voucher can also be used any time before the deadline, and hence there is no constraint on the maximum use of LPG. For reasons of simplification, the model has not been designed to cover these obvious cases where the health treatment is extremely effective. Finally, remember that $0 < \frac{p_d}{p_m} \leq 1$ since p_d is the discounted price while p_m is the market price. Considering all these arguments, we obtain the sign of the derivative.

We now examine how the impact of h on Δu varies for different levels of salience of health information. We use (15) evaluated at the initial preferences for LPG$\theta = \bar{\bar{\theta}}$. Considering that $\bar{\bar{\theta}} = \bar{\theta} + \bar{h} \cdot \gamma$ we can take the derivative of $\frac{\partial \Delta u}{\partial h}$ with respect to γ to obtain the cross-derivative:

$$\frac{\partial^2 \Delta u}{\partial h \partial \gamma} = \ln\left(\frac{2(1-\bar{\bar{\theta}})}{1-2\bar{\bar{\theta}}\frac{p_d}{p_m}}\right) + \gamma \frac{h \cdot (2\frac{p_d}{p_m}-1)}{(1-2\bar{\bar{\theta}}\frac{p_d}{p_m})(1-\bar{\bar{\theta}})} > 0 \qquad (16)$$

This inequality holds under exactly the same conditions as the inequality in (15).

Before concluding this analysis, let us further examine the reaction of Δu to a change in the discounted offer price p_d. Since this price can be obtained only when the household effectively uses the voucher, a lower p_d makes voucher use more attractive:

$$\frac{\partial \Delta u}{\partial p_d} = -\frac{(1-\theta)2\theta}{(1-2\theta)p_m} < 0 \qquad (17)$$

This inequality only requires Assumption 1 (see Assumptions below). The negative relationship between WTP and the required consumption is thus also reflected in the lower propensity of voucher use (implying the doubling of consumption) for higher p_d.

Finally, note that — as opposed to WTP — the propensity of voucher use is unrelated to the budget B, since it enters in the same way in both $U_1$and U_0 and hence cancels out:

$$\frac{\partial \Delta u}{\partial B} = 0 \qquad (18)$$

Assumptions

This section provides an overview of the three main assumptions referred to above:

1. Doubling LPG consumption (as imposed in the experiment) is theoretically possible, i.e., the consumption of other goods does not fall below 0 for all possible prices $p_d \in [0.5p_m, p_m]$ and θ. Formally,

   $$B - 2g^*(p_m, \theta) \cdot p_d > 0, \forall p_d, \forall \theta$$

   Using Equation (3) this further implies: $1 - 2\theta > 0, \forall \theta$.

2. The treatment $d \in [0,1]$ does not alter γ directly, i.e., health messaging only affects health knowledge h, but not the salience of this knowledge:

   $$\frac{\partial \gamma}{\partial d} = 0$$

   This is certainly true for the main variable we think of in this context, namely gender, but also smoke exposure more broadly, which cannot change immediately, i.e., prior to the household's reactions with respect to consumption or stated WTP that we are assessing here.

3. The preference increase for LPG as a result of the intervention is not so strong that the household would want to increase its LPG use by more than 100 %. This implies that

the requirement we impose on the household to *at least double* its LPG consumption can be treated in the model as a requirement to *double* consumption:

$$\bar{g} = max\{2g^*(p_m, \bar{\bar{\theta}}), g^*(p_d, \theta)\} = 2g^*(p_m, \bar{\bar{\theta}}) \to 2\bar{\bar{\theta}} > 0$$

The alternative case is of course possible, but including this option into the model would make the model more complex, while not changing anything substantially. This is because households willing to consume more than $2g^*(p_m, \bar{\bar{\theta}})$ will have an even higher propensity to use the vouchers.

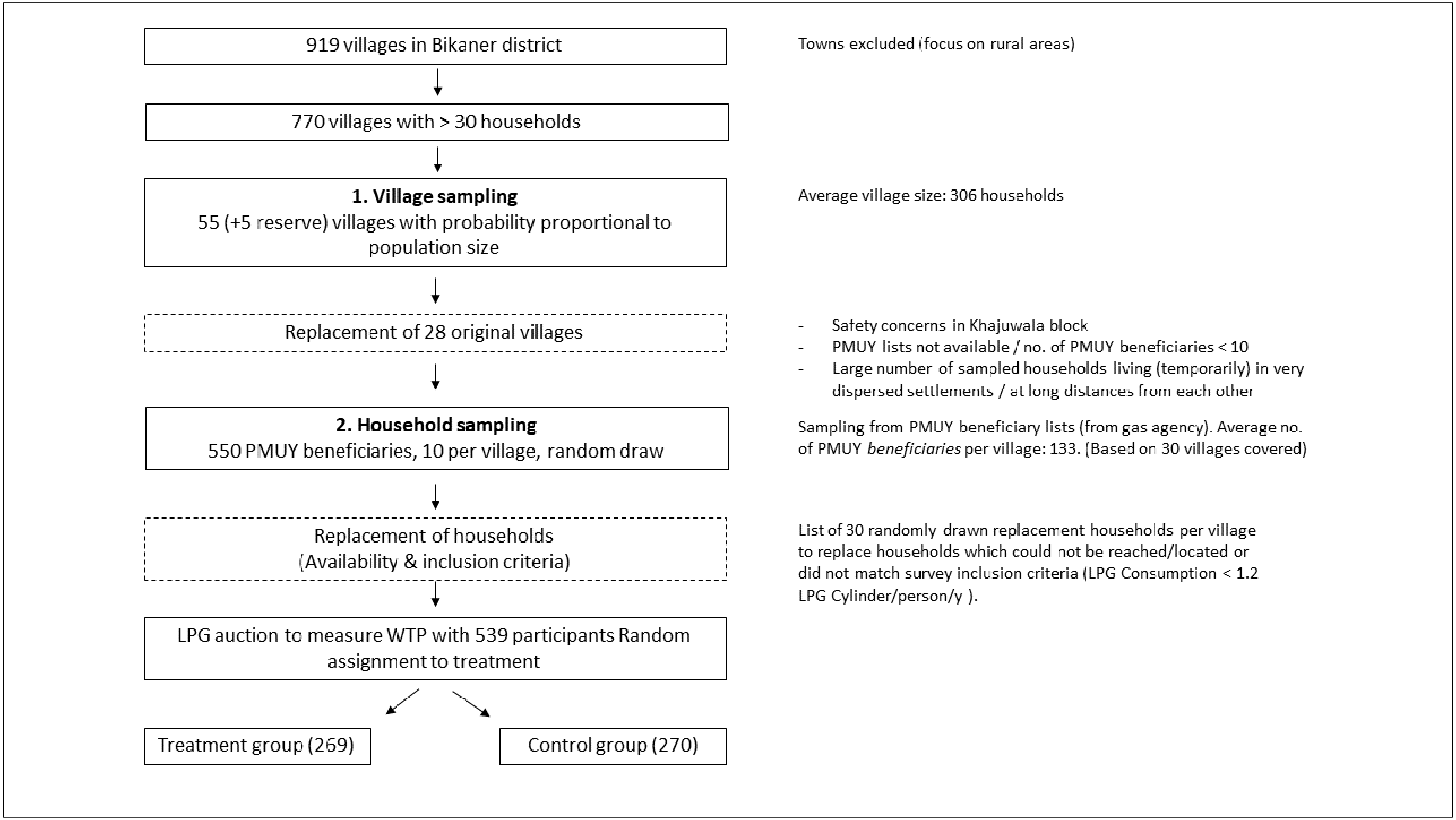
Appendix F Power calculation and sampling protocol for LPG experiment

We determined our sample size based on the aim to detect an additional WTP for LPG associated with the intervention of ₹12 Indian rupee or larger. ₹12 corresponded to 2.5 % of the regulated market rate for a standard size LPG cylinder when the field study started (= ₹480). Assuming that the pooled standard deviation of WTP would be ₹60 (based on a pilot among 21 households), the price difference of ₹12 corresponded to a between-groups effect size of d=.2 (small). To obtain statistical power at the recommended 0.8 level with alpha set at 0.05 for a two-tailed test, a sample of 393 would be required. However, if the variance is higher, the required sample size increases substantially. We hence aimed at 500 usable observations for the experiment. Adding 10 % to account for different kinds of data problems which may arise resulted in 550 planned interviews. We hence sampled 55 villages in Bikaner district with probability proportional to population size. Figure A 4 shows this district, in the state of Rajasthan. The protocol in Figure A 5 describes the sampling procedure in detail.

Figure A 4 Study area of Bikaner district, Rajasthan, India

Source: By Miljoshi, available on wikimedia commons under the CC BY-SA 3.0 license.

Figure A 5 Sampling protocol



Appendix G Summary statistics and balance tests for LPG experiment

Table A 12 Means and tests of treatment-control covariate balance

	Total mean	Control mean	Treatment mean	Difference b	t
Male	0.08	0.09	0.07	0.01	(0.62)
Age	28.55	28.29	28.81	-0.52	(-0.73)
Education	1.50	1.57	1.43	0.14	(1.43)
Household size	6.00	5.85	6.15	-0.30	(-1.53)
Hindu	0.97	0.98	0.96	0.02	(1.24)
Muslim	0.03	0.02	0.04	-0.01	(-1.02)
BPL	0.60	0.57	0.63	-0.06	(-1.27)
Expenditures	6752.59	6740.38	6764.75	-24.37	(-0.07)
Land	0.66	0.63	0.68	-0.05	(-1.15)
Asset index	-0.01	-0.04	0.01	-0.05	(-0.38)
Refills	0.91	0.90	0.92	-0.02	(-0.88)
LPG consumption	0.24	0.23	0.25	-0.01	(-0.99)
Wood quantity	45.75	47.63	43.85	3.78	(1.17)
Dung quantity	52.47	51.78	53.17	-1.39	(-0.38)
Random price	339.94	336.41	343.48	-7.06	(-1.29)
Content	0.45	0.46	0.44	0.01	(0.53)
Voucher validity	21.05	21.34	20.75	0.59	(0.37)
Subsidy	0.15	0.13	0.17	-0.05	(-0.96)
LPG convenience	1.49	1.48	1.49	-0.01	(-0.20)
Distance	0.46	0.48	0.44	0.04	(0.91)
Refill cost	0.90	0.91	0.90	0.01	(0.31)
Fin. restriction	0.77	0.79	0.75	0.05	(1.26)
Food taste	0.57	0.57	0.56	0.02	(0.38)
Safety	0.24	0.24	0.23	0.01	(0.28)
N	539	270	269	539	

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Table A 13 Means and tests of treatment-control covariate balance for voucher owners

	Total mean	Control mean	Treatment mean	Difference b	t
Male	0.10	0.12	0.07	0.05	(1.49)
Age	28.31	27.97	28.65	-0.67	(-0.73)
Education	1.52	1.55	1.50	0.05	(0.37)
Household size	5.89	5.75	6.03	-0.29	(-1.22)
Hindu	0.97	0.99	0.94	0.05***	(2.60)
Muslim	0.03	0.01	0.05	-0.05**	(-2.40)
BPL	0.57	0.58	0.57	0.01	(0.14)
Expenditures	6511.90	6405.41	6619.86	-214.46	(-0.44)
Land	0.66	0.67	0.65	0.01	(0.24)
Asset index	-0.09	-0.14	-0.04	-0.10	(-0.65)
Refills	0.91	0.89	0.93	-0.04	(-1.14)
LPG consumption	0.25	0.24	0.26	-0.02	(-1.09)
Wood quantity	46.15	47.54	44.72	2.82	(0.68)
Dung quantity	51.99	49.48	54.56	-5.07	(-1.08)
Random price	305.43	301.51	309.40	-7.89	(-1.51)
Content	0.43	0.42	0.44	-0.02	(-0.61)
Voucher validity	20.61	20.42	20.82	-0.40	(-0.20)
Subsidy	0.17	0.14	0.21	-0.08	(-1.14)
LPG convenience	1.50	1.53	1.47	0.06	(0.66)
Distance	0.47	0.44	0.50	-0.06	(-1.08)
Refill cost	0.88	0.87	0.90	-0.03	(-0.84)
Fin. restriction	0.74	0.75	0.72	0.03	(0.56)
Food taste	0.53	0.56	0.51	0.06	(0.97)
Safety	0.25	0.26	0.24	0.02	(0.43)
WTP for LPG	389.83	382.88	396.91	-14.03*	(-1.87)
Voucher value	174.64	178.59	170.60	7.99	(1.53)
N	303	153	150	303	

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Table A 14 Variable definitions and summary statistics

Variable	Definition	Count	Mean	Std. Dev.	Min	Max
Dependent variables						
WTP	Willingness to pay for LPG	539	356.79	71.34	200.0	750.0
Voucher use	Dummy = 1 if individual used voucher before the household-specific expiry date	296	0.35	0.48	0.0	1.0
Key explanatory variable						
Health information	Dummy = 1 if individual is exposed to health information	539	0.50	0.50	0.0	1.0
Other variables						
Voucher	Dummy = 1 if individual received voucher	539	0.56	0.50	0.0	1.0
Voucher validity	Days until voucher expiry	538	21.05	18.22	3.5	172.0
Voucher value	Voucher value (INR)	303	174.64	45.44	5.0	235.0
Male	Dummy = 1 if individual is male	539	0.08	0.27	0.0	1.0
Age	Age of the individual	539	28.55	8.18	18.0	65.0
Education	Education (Categorical, levels 1-7)	539	1.50	1.16	1.0	7.0
Household size	Number of persons sharing one kitchen	538	6.00	2.31	2.0	20.0
Hindu	Dummy =1 if individual is Hindu	539	0.97	0.17	0.0	1.0
Muslim	Dummy =1 if individual is Muslim	539	0.03	0.17	0.0	1.0
BPL	Dummy = 1 if household holds a BPL card	508	0.60	0.49	0.0	1.0
Expenditures	Household consumption expenditures (INR/month)	521	6752.59	4184.69	400.0	50000.0
Land	Dummy = 1 if household owns land	539	0.66	0.48	0.0	1.0
Asset index	Weighted index of asset ownership	539	-0.01	1.42	-1.4	6.6
Refills	Dummy = 1 if household buys LPG refills	539	0.91	0.29	0.0	1.0
LPG consumption	Estimated LPG consumption HH (cylinder/month)	489	0.24	0.15	0.0	1.7
Wood quantity	Wood quantity used (kg/week)	536	45.75	37.29	0.0	350.0
Dung quantity	Dung quantity used (kg/week)	537	52.47	42.11	0.0	350.0
Content	Estimated content current cylinder (in %)	468	0.45	0.25	0.0	1.0
Subsidy	Dummy = 1 if household buys subsidized cylinders	232	0.15	0.35	0.0	1.0
LPG convenience	Convenience LPG vs. trad. cooking (1-Better, 2-Similar, 3-Worse)	539	1.49	0.74	1.0	4.0
Distance	Dummy = 1 if distance explains low LPG usage)	539	0.46	0.50	0.0	1.0
Refill cost	Dummy = 1 if refill costs explain low LPG)	539	0.90	0.30	0.0	1.0
Fin. restriction	Refill costs as main hindrance to regular LPG consumption (respondents share)	539	0.77	0.42	0.0	1.0
Food taste	Dummy = 1 if taste of food explains low LPG)	539	0.57	0.50	0.0	1.0
Safety	Dummy = 1 if safety explains low LPG)	539	0.24	0.42	0.0	1.0
Severe effects	Dummy = 1 if aware of severe effects from IAP	503	0.31	0.46	0.0	1.0
Slight effects	Dummy = 1 if aware of slight effects from IAP	503	0.53	0.50	0.0	1.0
No effects	Dummy = 1 if not aware of any effects from IAP	503	0.16	0.37	0.0	1.0
IAP diseases	Share of six IAP-related diseases correctly identified (in %)	539	0.34	0.28	0.0	1.0
All diseases	Share of ten diseases correctly identified as either IAP-related or not	539	0.51	0.15	0.1	0.9
Observations		539				

Sample restricted to respondents taking part in the WTP. Experiment. IAP = Indoor Air Pollution.

Appendix H Protocol and material for WTP elicitation and LPG experiment

As explained in the main document, in order to ensure that survey participants would well understand the procedure leading to our measurement of WTP, we first ran the process with a relatively cheap item (a piece of soap) that respondents had to buy if their stated WTP was above a randomly drawn offer price. We then repeated the same procedure with a more expensive good (an LED bulb). This means that once the process was implemented for LPG, respondents had already gained significant experience with the procedure. In this Appendix we provide the protocol used for the WTP measurement of the piece of soap and the complete protocol for the LPG WTP experiment. The WTP measurement for the LED bulb was more or less identical to the one for soap, except for some reference to the experience the respondent already had with soap. It is therefore not shown here. The following questions and instructions were communicated verbally by the enumerator to the respondent. Occasional instructions in italics were directed to the enumerator. The enumerators carried these instructions on their mobile phone and the survey application of Qualtrics we had prepared took them automatically from one step to the next.

H1 Protocol for measuring the willingness to pay for soap

Introduction

In this survey we will mainly ask you things about your energy use for cooking and lighting. In this context, we will also ask you to take a couple of decisions about real products. For this reason, before we start, we would like to go through a little exercise, so you can see how these decisions will work. I will now explain to you how it works.

In the following, you can purchase an item, as follows: First, you (participant) say the maximum amount you are ready to pay for it. The actual price will be unknown, but we will tell you the range of prices possible. We will then find out, at which price the good will be made available to you for purchase. To do so, we have prepared cards with prices within the possible range.

I will ask you to draw one card that will then show the relevant price. If this price is less than your originally stated maximum amount you would like to pay, then you will have to purchase the good at this price. If the price is higher than the amount you stated earlier, you cannot purchase it.

Maybe this procedure seems a bit complicated to you. But it makes sure that it is optimal for you to tell us your true willingness to pay. You cannot do better by stating a lower or higher price than you actually would be ready to pay.

Let us make an example for the procedure: You say you would be ready to pay up to ₹4, and the price on the card drawn is ₹7. The item will not be sold. If your price was ₹10, the item is sold at ₹7.

Note that if what you state is higher than the price drawn, this is an agreement to buy the good, and that if your stated amount is below the price, there will be no sale. Do you have any questions so far?

Let us now make the real run with a piece of soap. Are you willing to participate?

- □ Yes
- □ No

→ If *No* is selected, the survey ends at this point.

Bidding procedure

Here is a soap. The price at which it will be made available to you will be between ₹1 to ₹10, prices within this range are printed on the cards that you can see here. Now what is the maximum amount you are ready to pay to get it?

→ Participant states a price.

I would like to remind you that if you state an amount that is higher than the price which will be determined in a minute, this is an agreement to purchase the soap, and that if your amount is below the price there will be no sale. Would you like to adjust your amount now?
If YES, go back to last question and adjust amount.

What is the maximum amount the participant is willing to pay? Please write down the price that was stated in rupees. ____________

We now determine the price at which the good is made available for you in a random manner. Please turn one of the cards upside.

→ The participant turns up one of the number cards in front of her. The cards show the numerical values 2, 4, ...10.

What is the actual price on the card? Please select the actual price on the card in the drop-down list.

→ The survey software calculates difference between bid (stated WTP) and offer price (randomly drawn price). Depending on the difference being positive or not, it redirects the enumerator to instruction A or B, with filled-in numerical values.

A The respondent cannot buy the soap
Your maximum amount of ₹[...] was lower than the actual price of ₹[...] which you have drawn from the cards. This means the price you are ready to pay is not as high as the sales price we found here. Therefore, you cannot buy the soap.

B The respondent can buy the soap
You are ready to pay an amount of ₹[...]. This is higher than (or same) as the actual price of the soap, which you have drawn from the cards, which is ₹[...]. This means you will purchase the soap for the price of ₹[...] now.

Did the participant agree to buy the soap?

- ◻ Yes
- ◻ No, because

H2 Experimental Protocol to measure the effect of health messaging on the WTP for LPG

Introduction

Now we would now like to carry out an exercise on LPG, which is similar to the ones with the soap and LED carried out before. We would like you to bid for one cylinder of LPG. You will have the chance to buy a cylinder at a price somewhat below ₹480. Let us remind you that this is about a real purchase and that your decision will be truly implemented. Do you agree to participate? In case you wish to consult with someone else in the family, you can do so.
Wait in case the respondent wants to call another person to participate for the rest of the question.

- ◻ Yes
- ◻ No

→ If *No* is selected, survey software redirects enumerator to section 'Exit questions'.

Conditions

Please listen carefully to the conditions: The mechanism is basically the same as for the soap and the LED bulb. But as you can imagine, we cannot carry the gas cylinders with us. Therefore, we will work with vouchers.

- Voucher: The current subsidized price for a cylinder of LPG (subsidy comes on your bank account) is about ₹480. If the price we draw is below that (₹480), we give you a voucher which will cover the difference.
- Time period: There is another important difference to a normal order: you have to use the remaining LPG more intensively than before, such that you collect the new cylinder earlier than usual or than you might have planned. For your case this concretely means, that the cylinder that we offer you must be collected before […] days.

→ We fixed a specific deadline for each household that would require this household to consume the remainder of the LPG in the cylinder currently in use twice as quickly than under normal circumstances. The deadline was determined by the survey tool based on the information about the family's existing LPG consumption and the remaining time for using up the current cylinder using the information provided at the outset in the screening questions. If this estimate could not be meaningfully interpreted (for instance, because the LPG connection was established only very recently), the household was directly asked to make a prediction on when they would need a refill and this prediction was halved to replace the estimate. The next working day after the end of this period constituted the deadline for the validity of the voucher.

Information intervention

Before we start, let me inform you that ...
Present the information to the respondent and show the poster together with it.

→ Automated randomization through the survey app, directly displaying either the health frame or the alternative frame to the enumerator. The Enumerator presents the information (either of the frames) and shows the illustrating poster together with it. See all information material used for frames in H3.

Bidding procedure

Let us now turn to the bidding procedure. First let us find out what the maximum amount is that you are ready to pay for one cylinder of LPG, under the conditions I explained to you. Remember that it is optimal for you to tell us your true willingness to pay. You cannot do better by stating a lower or higher price than you actually would be ready to pay.

Now what is the maximum amount you are ready to pay for the cylinder?
Please note the price stated in rupees. ______________________________

I would like to remind you that if you bid above the price we will just determine, this is an agreement to buy an LPG cylinder, and that if your bid is below the price you cannot buy LPG at special conditions. Would you like to adjust your bid now?
If yes go back to last question.

We now determine the price at which the good is made available for you in a random manner. Please turn one of the cards upside.

→ The participant turns up one of the number cards in front of her. The cards represent numerical values between 240 and 480, at intervals of 10 (starting from 245).

Note actual price from the card in rupees. ________________________________

→ Survey software calculates difference between bid (stated WTP) and offer price (randomly drawn price). Depending on the difference being positive or not, it redirects the enumerator to instruction A or B, with filled-in numerical values.

A LPG voucher

You are ready to pay an amount of ₹[...], this is higher than (or same) as the actual price, which you have drawn from the cards, which is ₹[...],. This means you will be able to buy a cylinder of LPG at the price of ₹[...], now. We will make this possible by giving you a voucher, which covers the difference between this price and ₹480 [the normal subsidized cylinder price]. In your case this is ₹480 minus [offer price], equals ₹[calculated voucher value]. For this we have an agreement with [name local distributor]. You can go there or order via phone/SMS and then use the voucher like cash. As we have explained before, there is a special condition of this voucher: You have to use the voucher to buy the next LPG cylinder before [calculated deadline] days.

Please take the voucher and fill it in:

- Name of interviewed person
- Her full address
- Voucher amount: (₹480 – ₹[offer price]) , this is ₹[calculated vouchervalue]
- Valid until: Today's date + [calculated time to used up current cylinder] days

Explain very clearly that they have to use the voucher until this date, because after this date it will not be valid anymore, the voucher will become useless.

Please enter the voucher number here: ______________________________

Please take a photo of the voucher.

B No LPG voucher

The amount you are ready to pay for one cylinder ₹[...] is lower than the actual price of ₹[...] which you have drawn from the cards. This means what you would like to pay is not enough to buy a new cylinder under these special conditions. Therefore, you cannot buy the LPG cylinder now.

Exit questions

Q1 Considering the impact on health, compared to traditional cooking stoves, the LPG-based cooking is:

- □ Better (1)
- □ Similar (2)
- □ Worse (please specify) (3):____________________
- □ Don’t know (4)

→ Depending on the answer, the Enumerator is directed to an additional questions listed below as follows…
to Q2 if the answer is “Better” (1)
to Q3 if if the answer is “Similar (2)
to Q4 if if the answer is “Don’t know” (4)
(no additional question on health impact if answer is “Worse” (3))

Q2 Let us talk a bit more about that. If cooking with firewood and/or dung affects the health, how severe is that? I will read out 2 statements now, please which one corresponds to your opinion:

- □ Cooking with dung cakes/firewood causes coughing and irritated eyes, but this health impact is not a severe problem.
- □ Cooking with firewood/dung cakes over a long time can cause very severe health problems.
- □ Other (please specify):_________

Q3 Let us talk a bit more about that. I read out 2 statements now, please tell me which one corresponds to your opinion:

- □ No, I do not think that cooking with firewood and/or dung cakes causes any health problems.
- □ Cooking with dung cakes/firewood causes coughing and irritated eyes, but this health impact is not a severe problem

Q4 Let us talk a bit more about that. I read out 3 statements now, please tell me which statement corresponds to your opinion:

- ◻ No, I do not think that cooking with firewood and/or dung cakes causes any health problems.
- ◻ Cooking with dung cakes/firewood causes coughing and irritated eyes, but this health impact is not a severe problem.
- ◻ Cooking with firewood/dung cakes over a long time can cause very severe health problems.

Q5 I am going to name lot of different health problems now. Some of them have to do with the smoke from the chulha, others don't have anything to do with it at all. For each one, could you tell me whether you think that cooking from firewood or dung cakes can make it more likely to suffer from this disease?

Disease	Yes	No
Arthrosis / Jodbandi	◻ ◦	◻ ◦
Heart diseases	◻ ◦	◻ ◦
Lung Cancer	◻ ◦	◻ ◦
Osteoporosis (bone atrophy)	◻ ◦	◻ ◦
Cataract / Motyaabind	◻ ◦	◻ ◦
Pneumonia	◻ ◦	◻ ◦
Problems for physical child development	◻ ◦	◻ ◦
Dengue fever	◻ ◦	◻ ◦
Diarrhea / Haija	◻ ◦	◻ ◦
Stroke / Aaghaat	◻ ◦	◻ ◦

Q6 Do you feel any discomfort from cooking with firewood and/or dungcakes? Please select the statement which fits best.

- ◻ No, I do not feel any discomfort.
- ◻ Cooking with dung cakes/firewood causes me to caugh more and have irritated eyes, but it is not a problem for me.
- ◻ I feel discomfort in my lungs and eyes and I have already experienced severe health problems, which have to do with the smoke from the chulha.
- ◻ Don't know

H3 Information material used for frames

While this appendix contains English versions of the visualizing posters and texts, the material used in the field was in Hindi language.

Health frame (text for enumerator and poster)

Before we start let me inform you that LPG is very different from firewood and dung cake regarding the health effects of these fuels. You have certainly observed that when cooking with the chulha – especially indoors and with bad ventilation – there is a lot of pollution in the air (show picture of cooking woman). According to studies from different universities and research institutions, this pollution causes many more health problems than may be directly observable for the person who cooks and her family. As opposed to what one may think, the effects are not limited to temporary coughing, tearing eyes and throat ache, but also include several severe diseases:

- Generally, many people in India die much earlier than normal from disease which is caused by air pollution from cooking with solid fuels.
- A large number of people, for instance, die prematurely due to a stroke. This occurs when blood flow to an area of the brain is cut off. Every 4th case of death from stroke is due to breathing in the polluted air over a long period of time.
- Similarly, indoor air pollution increases the risk of developing lung cancer or heart disease significantly. It is like smoking a very large amount of cigarettes every day, you can see on the picture what can happen to the lung *(show pictures lung diseases and heart diseases)*.
- It also increases the chances of getting a cataract/motyaabind *(show picture eye diseases).* If untreated, cataract/motyaabind can lead to blindness.
- And it can hinder the development of (the) children. Women and small children are the most affected by the pollution. When small children die from acute lower respiratory infections like pneumonia, this is due to indoor air pollution in more than half of the cases *(show picture development of child).* Of course, ventilation helps to reduce these risks. Having an open window and a chimney hood or cooking outside is therefore helpful. But according to available academic studies, the remaining risks are often considerable and should not be underestimated. When cooking on a chulha, the danger of being hit by the severe diseases mentioned above is usually still much higher than otherwise.

Figure A 6 Visualizing poster health frame.

Alternative frame (text for enumerator and poster)

Before we start, let me give you some information about how liquefied petroleum gas or LPG, your cooking gas, is produced. LPG is a fossil fuel. Sometimes it is recovered naturally, directly from the ground. Another way of producing LPG is by refining it from crude oil. Crude oil is a thick and black liquid. It is a mixture of different chemicals which can be used as fuel because they burn well. Most crude oil is found by drilling down through rocks on land or off-shore at the bottom of the ocean.

- Look, we have a picture of an oil field off the coast of Mumbai. The oil gets pumped up from a deep hole in the ocean floor (*show picture of oil field off the coast of Mumbai*).
- Crude oil cannot be used as a fuel as it is. Therefore, the crude oil must be transported to a so-called oil refinery as a first step. This can best be done through a crude oil pipeline, which pumps the crude oil from the oil field to a refinery *(show picture of crude oil pipe)*. This pipeline transports crude oil from the Barmer district, Rajasthan to Salaya, Gujarat.
- At the oil refinery, the crude oil is heated and then distilled to separate it into different petroleum products *(show picture of oil refinery)*. These include gasoline for cars, ship fuel and the petroleum gas used for cooking.
- But gas takes up a lot of space. To make storage easier, the gas is liquefied by compressing with high pressure. This is why your cooking gas is called liquefied petroleum gas or LPG.
- Then the liquefied gas is transported to a bottling plant. There it gets filled into the cylinders that you know *(show picture of bottling plant).* They are small enough for relatively easy transport. Since the gas is still liquid, it does not take up too much room.
- As a last step, LPG distributors deliver the LPG cylinders to customers in local markets *(show picture of delivery)*.
- In some major cities, households do not have to buy the LPG bottled up in cylinders, but instead receive gas through a pipeline in their kitchen *(show picture of woman with stove and gas pipeline)*.
- If you release the liquid from the cylinder by turning on your appliance, it turns back into gas.

Figure A 7 Visualizing poster alternative frame.

Appendix I Offer price distribution and voucher use

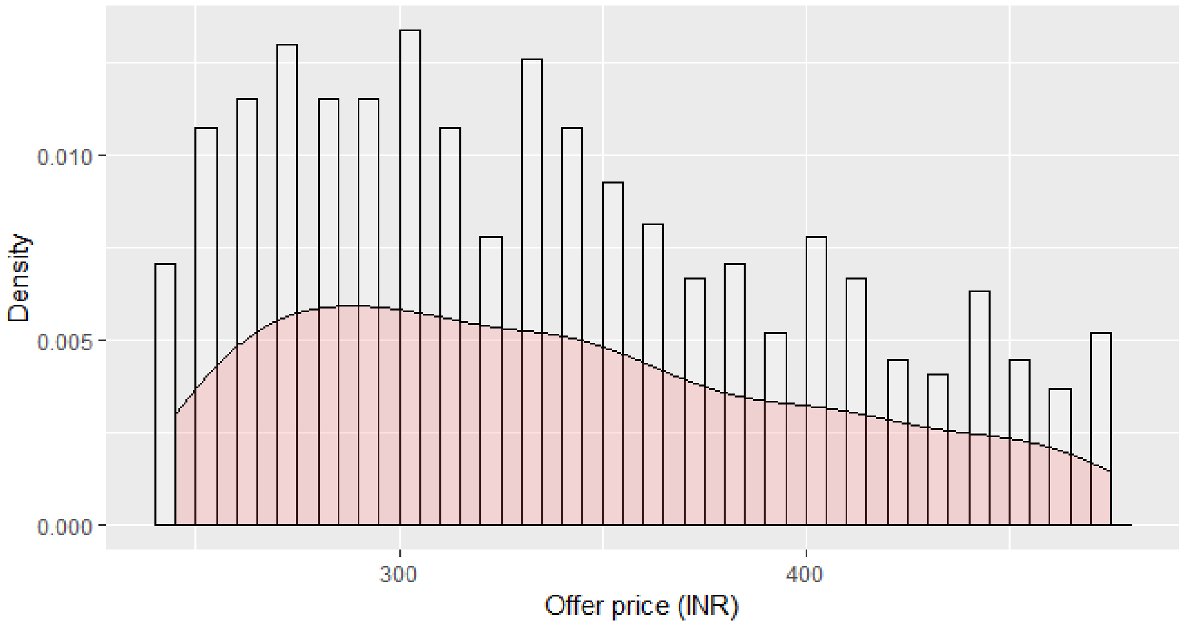
Offer Prices in the WTP eliciting mechanism

Enumerators determine the offer prices pd used in the WTP eliciting mechanism by drawing a random piece from a set of price cards covering the range from ₹245 to ₹475 in steps of ₹5.

The choice of the price range is based on the following reflection: Even if a household's currently used cylinder was full at the time of the survey and even if its demand for LPG was completely inelastic (i.e., it does not speed up consumption due to price reductions), it would be left with a maximum of 50 % of the cylinder content (with a market value of ₹240) at the expiry date of the voucher, i.e., when the cylinder is to be replaced by a full one. All households should thus accept to replace their currently used cylinder by a full one if they are given a compensation C = ₹480 − ₹240 = ₹240, and a higher discount should not be necessary in our context.

Figure A 8 shows the empirical distribution of the prices. While prices were drawn from the full range of possible values, their distribution is right-skewed. Offer prices below the mean (₹339) are more frequent than prices that are higher than this average. This is surprising as an approximately uniform distribution of offer prices should have been expected. A chi-square test comparing the observed frequencies to the expected frequencies under a discrete uniform distribution clearly rejects the null hypothesis that these distributions are equal (p = 0.000).

Figure A 8 Distribution of offer prices



Histogram with heights of the bars representing observed frequencies of offer prices and density curve as approximation of the proportion of values in certain price ranges. INR stands for Indian rupee.

This raises some doubts regarding the random selection of offer-prices. It cannot be excluded for instance that, in some cases, enumerators made the selection only among higher discount values in order to provide extra benefits to the household. However, since WTP is measured before offer prices are drawn, this should not affect our main results.

Offer Prices and voucher use probability

This section examines the effect of the randomly determined offer price in more detail. Table A 15 shows the results of a logistic regression estimation that includes the voucher value, i.e., the offered price discount D $(= p_m - p_d)$ as a continuous variable (odds ratios displayed).

Column 1 reports the odds ratio for the uncontrolled comparison between treatment and control group as a baseline, corresponding to Table 8, Column 1 in Chapter 7.5.4. As discussed there, the estimate indicates that the odds of using the voucher are 1.44 times larger for a household that received the health messaging than for a household that did not. Column 2 shows that the treatment effect is not much affected by the additional inclusion of the offer price. The odds ratio increases from 1.44 to 1.72. This corresponds to a change in the predicted probability of voucher use from 0.06 for the model in Column 1 to 0.08 for the model in Column 2. Furthermore, the estimate becomes more precise. Generally, the inclusion of prices substantially increases the precision of the model and its capacity to correctly predict the use or non-use of the voucher. The effect on the quality of the prediction is similar to the effect of the inclusion of price dummies in Table 8 in the main manuscript.

The discount itself has a robust and quite sizeable effect. On average, a price reduction of ₹20 increases the odds of using the voucher by a factor of 1.36. This corresponds to an increase in the predicted probability of using the voucher by 0.04.

In Column 3 and 4 we allow the price reduction to interact with the treatment effect and add further controls. Measured in terms of odds ratios, the interaction term is just at the border of significance. However, this is not very meaningful because, when the discount is close to zero, almost no respondent uses the voucher so that even a tiny absolute effect of health messaging appears like a huge effect in relative terms.

Rather than to interpret the interaction term in Table A 15, we thus move to a graphical illustration of the probability of voucher use for different treatment conditions and different discount values. Using the regression in Column 4, Figure A 9 shows how the predicted probability of voucher use increases with rising discounts (depicted in steps of ₹20) for both the treated and the untreated. Comparing the lines for these two groups, we find no systematic reduction in the distance between treated and non-treated for increasing voucher values. The marginal effect of the discount is also not changed by the treatment (p = 0.66).[100] On average, across all observed values in the sample, health messaging increases the probability of voucher use by about 0.1. Differences are most clearly significant for intermediate voucher values.

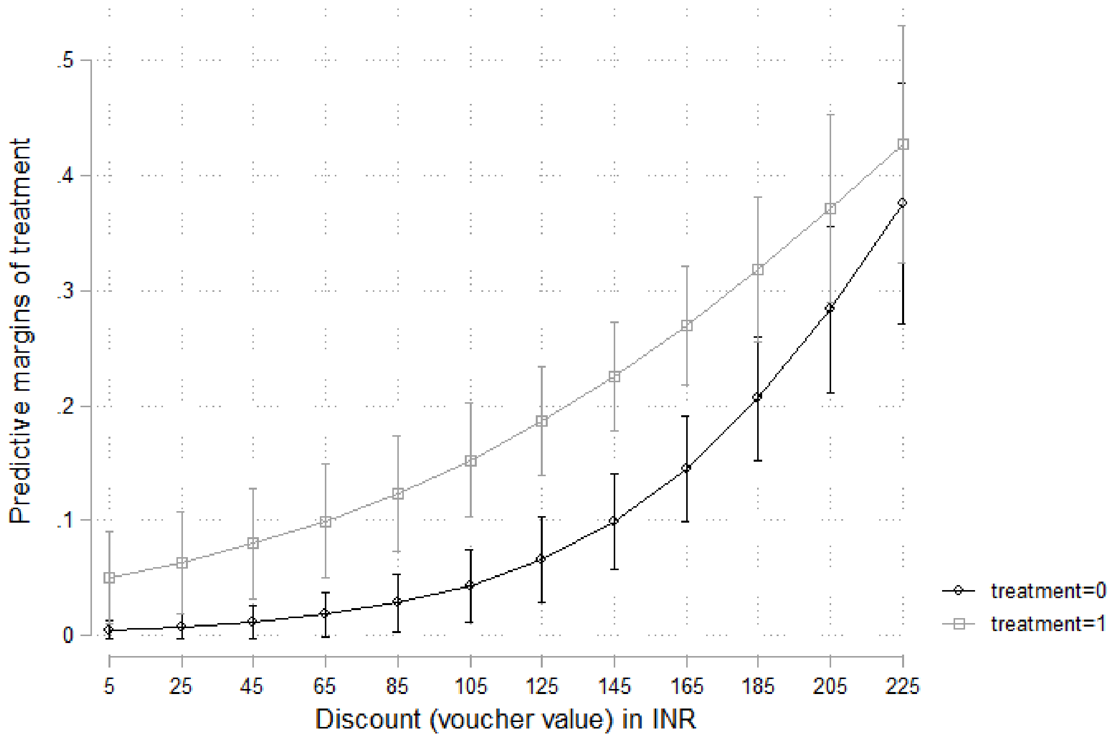
[100] The data and code required to replicate all findings reported in Chapter 7 and Appendix I is available here: https://doi.org/10.1371/journal.pone.0231931.s006.

Table A 15 Joint effect of health information on voucher use

	(1)	(2)	(3)	(4)
Health message	1.444*	1.724**	7.633**	11.421**
	(0.095)	(0.020)	(0.031)	(0.029)
Discount (per 20 INR)		1.360***	1.516***	1.564***
		(0.000)	(0.000)	(0.000)
Discount X Health message			0.843*	0.822
			(0.097)	(0.106)
Male				2.906**
				(0.023)
Content				0.548
				(0.407)
Voucher validity				0.996
				(0.680)
Asset index				1.122
				(0.219)
Land				1.221
				(0.481)
LPG distance				1.024*
				(0.050)
Fin. restriction				1.400
				(0.314)
Education				1.019
				(0.874)
Age				0.981
				(0.289)
Household size				0.889*
				(0.086)
Months since LPG adoption				1.024
				(0.181)
Constant	0.203***	0.017***	0.006***	0.007***
	(0.000)	(0.000)	(0.000)	(0.000)
N	532	531	531	449
Area under the ROC curve	55%	73%	73%	77%

Logit models with odds ratios, * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. p-values in parentheses. Lack of data on the additional variables included in Columns 2 to 4 leads to a reduction in the number of observations.

Figure A 9 Predicted Probability of voucher use



Logistic regression model as estimated in Column 4 of Table A 15 and 90% CIs.

Comparing the price effect and the treatment effect

Figure A 9 also allows us to compare the change in the predicted probability of voucher use driven by the treatment to the change induced by different discount values. For very low voucher values (at the left of the graph) health messaging increases the probability of voucher use by about 0.05. To reach the same effect size, the voucher value must be increased by ₹100 (from ₹5 to ₹105). In the middle part of the graph, the treatment effect appears somewhat stronger, but the slope of the curve of the non-treated is steeper, implying that a further discount matters more, too. At a discount value of ₹125, for instance, the health message increases the probability of a voucher use by almost 0.15, but the same effect can be reached by increasing the discount by ₹60, i.e., a lesser amount than before, from ₹125 to ₹185. On average across the range of observed values in the sample, increasing the discount by ₹40 (= 8.3 % of the current subsidized price of a new cylinder) increases voucher use by about 0.1, and thus corresponds to the effect size of health messaging within the same model (Table A 15 Column 4).

REFERENCES

Aamaas, Borgar; Marianne T. Lund, Gunnar Myhre, Bjørn H. Samset, Camilla W. Stjern & Steffen Kallbekken (2018) The climate impacts of current black carbon and organic carbon emissions. *CICERO Report* 2018:08 (https://pub.cicero.oslo.no/cicero-xmlui/handle/11250/2502504).

AGECC (United Nations Secretary-General's Advisory Group on Energy and Climate Change) (2010) Energy for a sustainable Future: Summary Report and Recommendations. United Nations. New York (http://www.un.org/chinese/millenniumgoals/pdf/AGECCsummaryreport%5B1%5D.pdf).

Aguirre, Mariana & Gbenga Ibikunle (2014) Determinants of renewable energy growth: A global sample analysis. *Energy Policy* 69: 374–384.

Agurto Adrianzén, Marcos (2013) Improved cooking stoves and firewood consumption: Quasi-experimental evidence from the Northern Peruvian Andes. *Ecological Economics* 89: 135–143.

Aklin, Michaël; Chao-yo Cheng, Karthik Ganesan, Abhishek Jain, Johannes Urpelainen & Council on Energy, Environment and Water (2016) Access to Clean Cooking Energy and Electricity: Survey of States in India (ACCESS). Harvard Dataverse, V1, UNF:6:uyURSR27cisb1HRgFvrkZg== [fileUNF] (https://doi.org/10.7910/DVN/0NV9LF).

Akpalu, Wisdom; Isaac Dasmani & Peter B. Aglobitse (2011) Demand for cooking fuels in a developing country: To what extent do taste and preferences matter? *Energy Policy* 39(10): 6525–6531.

Al Iriani, Mahmoud A. & Mohamed Trabelsi (2016) The economic impact of phasing out energy consumption subsidies in GCC countries. *Journal of Economics and Business* 87: 35–49.

Allison, Paul David (2009) *Fixed effects regression models. Quantitative Applications in the Social Sciences* no. 160. Los Angeles: SAGE.

Anand, Rahul; David Coady, Adil Mohommad, Vimal Thakoor & James P. Walsh (2013) The Fiscal and Welfare Impacts of Reforming Fuel Subsidies in India. *IMF Working Paper* 13(128) (http://www.imf.org/external/pubs/ft/wp/2013/wp13128.pdf).

Andadari, Roos Kities; Peter Mulder & Piet Rietveld (2014) Energy poverty reduction by fuel switching. Impact evaluation of the LPG conversion program in Indonesia. *Energy Policy* 66: 436–449.

Arnold, J. MichaelE.; Gunnar Köhlin & Reidar Persson (2006) Woodfuels, livelihoods, and policy interventions: Changing Perspectives. *World Development* 34(3): 596–611.

Arnold, Michael; Gunnar Kohlin, Reidar Persson & Gillian Shepherd (2003) Fuelwood revisited: What has changed in the last decade? *CIFOR Occasional Paper* (39). Center for International Forestry Research.

Arrow, Kenneth; Bert Bolin, Robert Costanza, Partha Dasgupta, Carl Folke, C. S. Holling, Bengt-Owe Jansson, Simon Levin, Karl-Goran Maler, Charles Perrings & David Pimentel (1995) Economic growth, carrying capacity, and the environment. *Ecological Economics* 15(2): 91–95 (https://EconPapers.repec.org/RePEc:eee:ecolec:v:15:y:1995:i:2:p:91-95).

Arze del Granado, Francisco Javier; David Coady & Robert Gillingham (2012) The Unequal Benefits of Fuel Subsidies: A Review of Evidence for Developing Countries. *World Development* 40(11): 2234–2248.

Aung, Ther W.; Grishma Jain, Karthik Sethuraman, Jill Baumgartner, Conor Reynolds, Andrew P. Grieshop, Julian D. Marshall & Michael Brauer (2016) Health and Climate-Relevant Pollutant Concentrations from a Carbon-Finance Approved Cookstove Intervention in Rural India. *Environmental science & technology* 50(13): 7228–7238.

Bagchi, Chandreyee; Paula Castro & Katharina Michaelowa (2016) Donor Accountability reconsidered: Aid Allocation in the Age of Global Public Goods. *CIS Working Paper* (87). Center for Comparative and International Studies (CIS), University of Zurich.

Baig, Taimur; Amine Mati, David Coady & Joseph Ntamatungiro (2007) Domestic Petroleum Product Prices and Subsidies: Recent Developments and Reform Strategies. *IMF Working Paper* 07(71). International Monetary Fund.

Bailis, Rob; Amanda Cowan, Victor Berrueta & Omar Masera (2009) Arresting the Killer in the Kitchen: The Promises and Pitfalls of Commercializing Improved Cookstoves. *World Development* 37(10): 1694–1705.

Bailis, Rob; Yiting Wang, Rudi Drigo, Adrian Ghilardi & Omar Masera (2017) Getting the numbers right: revisiting woodfuel sustainability in the developing world. *Environmental Research Letters* 12(11): 115002 (https://doi.org/10.1088/1748-9326/aa83ed).

Bailis, Robert; Rudi Drigo, Adrian Ghilardi & Omar Masera (2015) The carbon footprint of traditional woodfuels. *Nature Climate Change* 5(3): 266–272.

Bailis, Robert & Jasmine Hyman (2011) Developing enabling frameworks for the dissemination of clean-burning, fuel-efficient cookstoves. In: James Haselip, Ivan Nygaard, Ulrich Hansen & Emmanuel Ackom (eds) *Diffusion of renewable energy technologies: case studies of enabling frameworks in developing countries*. Technology Transfer Perspectives Series. Denmark: UNEP Risø Centre.

Barnes, Brendon; Angela Mathee & Elizabeth Thomas (2011) The impact of health behaviour change intervention on indoor air pollution indicators in the rural North West Province, South Africa. *Journal of Energy in Southern Africa* 22: 35–44 (http://www.scielo.org.za/pdf/jesa/v22n3/05.pdf).

Barnes, Brendon R. (2014) Behavioural change, indoor air pollution and child respiratory health in developing countries: a review. *International journal of environmental research and public health* 11(5): 4607–4618.

Barnes, Douglas F.; Keith Openshaw, Kirk R. Smith & Robert Van der Plas (1994) What Makes People Cook with Improved Biomass Stoves?: A Comparative International Review of Stove Programs. *World Bank Technical Papers Energy Series* (242). The World Bank. Washington D.C. (http://documents.worldbank.org/curated/en/738011468766789505/pdf/multi-page.pdf).

Barnes, Douglas F.; Hussain Samad & Sudeshna Ghosh Banerjee (2014) The Development Impact of Energy Access. In: Antoine Halff, Benjamin K. Sovacool & Jon Rozhon (eds) *Energy poverty: Global challenges and local solutions*. Oxford: Oxford University Press, 54–76.

Baumol, William J. (1972) On Taxation and the Control of Externalities. *American Economic Review* 62(3): 307–322 (http://www.jstor.org/stable/1803378).

Beaton, Christoffer; Ivetta Gerasimchuck, Tara Laan, Kerryn Lang, Damon Vis-Dunbar & Peter Wooders (2013) A Guidebook to Fossil-Fuel Subsidy Reform for Policy-Makers in Southeast Asia. The International Institute for Sustainable Development (https://www.iisd.org/gsi/sites/default/files/ffs_guidebook.pdf).

Becker, Gordon M.; Morris H. Degroot & Jacob Marschak (1964) Measuring utility by a single-response sequential method. *Behavioral Science* 9(3): 226–232.

Béland, Daniel & Robert Henry Cox (eds) (2011) *Ideas and politics in social science research*. New York, Oxford: Oxford University Press.

Bell, Andrew & Kelvyn Jones (2015) Explaining Fixed Effects: Random Effects Modeling of Time-Series Cross-Sectional and Panel Data. *Political Science Research and Methods* 3(01): 133–153.

Beltramo, Theresa; Garrick Blalock, David I. Levine & Andrew M. Simons (2015) The effect of marketing messages and payment over time on willingness to pay for fuel-efficient cookstoves. *Journal of Economic Behavior & Organization* 118: 333–345.

Benka-Coker, Megan L.; Wubshet Tadele, Alex Milano, Desalegn Getaneh & Harry Stokes (2018) A case study of the ethanol CleanCook stove intervention and potential scale-up in Ethiopia. *Energy for Sustainable Development* 46: 53–64.

Bensch, Gunther; Michael Grimm & Jörg Peters (2015) Why do households forego high returns from technology adoption?: Evidence from improved cooking stoves in Burkina Faso. *Journal of Economic Behavior & Organization* 116: 187–205.

Bensch, Gunther & Jörg Peters (2013) Alleviating Deforestation Pressures? Impacts of Improved Stove Dissemination on Charcoal Consumption in Urban Senegal. *Land Economics* 89(4): 676–698.

Bensch, Gunther & Jörg Peters (2015) The intensive margin of technology adoption--Experimental evidence on improved cooking stoves in rural Senegal. *Journal of health economics* 42: 44–63.

Bensch, Gunther & Jörg Peters (2019) One-Off Subsidies and Long-Run Adoption—Experimental Evidence on Improved Cooking Stoves in Senegal: Experimental evidence on improved cooking stoves in Senegal. *American Journal of Agricultural Economics* 47(5): 581.

Berkely Air Monitoring Group (2012) Stove Performance Inventory Report: Prepared for the Global Alliance for Clean Cookstoves. United Nations Foundation (http://berkeleyair.com/wp-content/publications/SPT_Inventory_Report_v3_0.pdf).

Berry, James; Greg Fischer & Raymond P. Guiteras (2019) Eliciting and Utilizing Willingness-to-Pay: Evidence from Field Trials in Northern Ghana. *Journal of Political Economy* (https://www.journals.uchicago.edu/doi/pdfplus/10.1086/705374).

Berthélemy, Jean-Claude (2006) Bilateral Donors' Interest vs. Recipients' Development Motives in Aid Allocation: Do All Donors Behave the Same? *Review of Development Economics* 10(2): 179–194.

Birol, Fatih (2014) Achieving Energy for All Will Not Cost the Earth. In: Antoine Halff, Benjamin K. Sovacool & Jon Rozhon (eds) *Energy poverty: Global challenges and local solutions*. Oxford: Oxford University Press, 10–20.

Bond, T. C.; S. J. Doherty, D. W. Fahey, P. M. Forster, T. Berntsen, B. J. DeAngelo, M. G. Flanner, S. Ghan, B. Kärcher, D. Koch, S. Kinne, Y. Kondo, P. K. Quinn, M. C. Sarofim, M. G. Schultz, M. Schulz, C. Venkataraman, H. Zhang, S. Zhang, N. Bellouin, S. K. Guttikunda, P. K. Hopke, M. Z. Jacobson, J. W. Kaiser, Z. Klimont, U. Lohmann, J. P. Schwarz, D. Shindell, T. Storelvmo, S. G. Warren & C. S. Zender (2013) Bounding the role of black carbon in the climate system: A scientific assessment. *Journal of Geophysical Research: Atmospheres* 118(11): 5380–5552.

Bradshaw, Michael J. (2014) *Global energy dilemmas: Energy security, globalization, and climate change*. Cambridge: Polity press.

Bridle, Richard; Lucy Kiston & Peter Wooders (2014) Fossil-Fuel Subsidies: A barrier to renewable energy in five Middle East and North African countries. *GSI Report*. The International Institute for Sustainable Development (https://www.iisd.org/gsi/sites/default/files/fossil-fuel-subsidies-renewable-energy-middle-east-north-african-countri%20%20%20.pdf).

Brooks, Nina; Vasundhara Bhojvaid, Marc A. Jeuland, Jessica J. Lewis, Omkar Patange & Subhrendu K. Pattanayak (2016) How much do alternative cookstoves reduce biomass fuel use? Evidence from North India. *Resource and Energy Economics* 43: 153–171.

Bruce, Nigel G.; Kristin Aunan & Eva A. Rehfuess (2017) Liquefied Petroleum Gas as a Clean Cooking Fuel for Developing Countries: Implications for Climate, Forests, and Affordability. *Materials on Development Financing* No.7.

Bruce, Nigel G. & Chen Ding (2014) Health Benefits from Energy Access in LMICs. In: Antoine Halff, Benjamin K. Sovacool & Jon Rozhon (eds) *Energy poverty: Global challenges and local solutions*. Oxford: Oxford University Press, 106–132.

Bruce, Nigel G.; Dan Pope, Eva Rehfuess, Kalpana Balakrishnan, Heather Adair-Rohani & Carlos Dora (2015) WHO indoor air quality guidelines on household fuel combustion: Strategy implications of new evidence on interventions and exposure–risk functions. *Atmospheric Environment* 106: 451–457.

Brundtland, Gro Harlem (1987) *Our common future: Report of the World Commission on Environment and Development. Oxford paperbacks*. Oxford University Press.

Bueno De Mesquita, Bruce; James D. Morrow, Randolph M. Siverson & Alastair Smith (1999) Policy Failure and Political Survival: The Contribution of Political Institutions. *Journal of Conflict Resolution* 43(2): 147–161 (http://jcr.sagepub.com/content/43/2/147.full.pdf).

Burnett, Richard T.; C. Arden Pope, Majid Ezzati, Casey Olives, Stephen S. Lim, Sumi Mehta, Hwashin H. Shin, Gitanjali Singh, Bryan Hubbell, Michael Brauer, H. Ross Anderson, Kirk R. Smith, John R. Balmes, Nigel G. Bruce, Haidong Kan, Francine Laden, Annette Prüss-Ustün, Michelle C. Turner, Susan M. Gapstur, W. Ryan Diver & Aaron Cohen (2014) An integrated risk function for estimating the global burden of disease attributable to ambient fine particulate matter exposure. *Environmental health perspectives* 122(4): 397–403.

Burniaux, Jean-Marc & Jean Château (2011) Mitigation Potential of Removing Fossil Fuel Subsidies: A general equilibrium assessment. *OECD Economics Department Working Papers* 853. OECD Publishing. Paris (https://doi.org/10.1787/5kgdx1jr2plp-en).

Buys, Piet; Uwe Deichmann, Craig Meisner, Thao Ton That & David Wheeler (2007) Country Stakes in Climate Change Negotiations: Two Dimensions of Vulnerability. *World Bank Policy Research Working Paper* (https://doi.org/10.1596/1813-9450-4300).

Buys, Piet; Uwe Deichmann, Craig Meisner, Thao Ton That & David Wheeler (2009) Country stakes in climate change negotiations: two dimensions of vulnerability. *Climate Policy* 9(3): 288–305.

Calvo-Gonzalez, Oscar; Barbara Cunha & Riccardo Trezzi (2015) When Winners Feel Like Losers: Evidence from an Energy Subsidy Reform. *World Bank Policy Research Working Paper* (https://openknowledge.worldbank.org/handle/10986/21998).

Cameron, Colin; Shonali Pachauri, Narasimha D. Rao, David McCollum, Joeri Rogelj & Keywan Riahi (2016) Policy trade-offs between climate mitigation and clean cook-stove access in South Asia. *Nature Energy* 1(1): 784.

Carbon Clear (2013) Darfur Efficient Cook-stove Project: Final Project Design Document. *The Gold Standard voluntary offset projects, project design document form (GS-VER-PDD)* Version 01 (https://mer.markit.com/br-reg/public/project.jsp?project_id=103000000002416).

Cashman, Sarah; Molly Rodgers, Melissa Huff, Rebe Feraldi & Ben Morelli (2016) Life-Cycle Assessment of Cookstove Fuels in India and China. *EPA/600/R-15/325*. U.S. Environmental Protection Agency. Washington, DC (https://nepis.epa.gov/Exe/ZyPDF.cgi/P100R4BI.PDF?Dockey=P100R4BI.PDF).

CCAC (Climate and Clean Air Coalition) (2019) Household Energy (https://www.ccacoalition.org/en/initiatives/household-energy).

Chafe, Zoë A.; Michael Brauer, Zbigniew Klimont, Rita van Dingenen, Sumi Mehta, Shilpa Rao, Keywan Riahi, Frank Dentener & Kirk R. Smith (2014) Household cooking with solid fuels contributes to ambient PM2.5 air pollution and the burden of disease. *Environmental health perspectives* 122(12): 1314–1320.

Chapman, Robert S.; Xingzhou He, Aaron E. Blair & Qing Lan (2005) Improvement in household stoves and risk of chronic obstructive pulmonary disease in Xuanwei, China: retrospective cohort study. *BMJ (Clinical research ed.)* 331(7524): 1050.

Chen, B H; C J Hong, Mrigendra Raj R Pandey & Kirk R Smith (1990) Indoor Air Pollution in Developing Countries. *World Health Statistical Quarterly* (43): 127–138.

Cheng, Chao-yo & Johannes Urpelainen (2014) Fuel stacking in India: Changes in the cooking and lighting mix, 1987–2010. *Energy* 76: 306–317.

Cheon, Andrew; Maureen Lackner & Johannes Urpelainen (2015) Instruments of Political Control: National Oil Companies, Oil Prices, and Petroleum Subsidies. *Comparative Political Studies* 48(3): 370–402.

Cheon, Andrew; Johannes Urpelainen & Maureen Lackner (2013) Why do governments subsidize gasoline consumption? An empirical analysis of global gasoline prices, 2002-2009. *Energy Policy* 56: 382–390.

Clean Cooking Alliance (2015) *Clean Cookstoves and Fuels: A Catalog of Carbon Offset Projects and Advisory Service Providers* (https://www.cleancookingalliance.org/resources/381.html).

Clean Cooking Alliance (2018a) Dymphna's Message for May 2018: Alliance News (http://cleancookstoves.org/about/news/05-31-2018-dymphna-s-message-for-may-2018.html).

Clean Cooking Alliance (2018b) Grants (http://cleancookstoves.org/funding-opportunities/grants.html).

Clean Cooking Alliance (2019a) *2018 Annual Report* (https://www.cleancookingalliance.org/resources/572.html).

Clean Cooking Alliance (2019b) Voluntary Performance Targets (https://www.cleancookingalliance.org/technology-and-fuels/standards/iwa-tiers-of-performance.html).

Clements, Benedict J.; David Coady, Sanjeev Gupta, Stefania Fabrizio, Trevor Alleyne & Carlo A. Sdralevich (eds) (2013) *Energy Subsidy Reform: Lessons and Implications*. Washington, D.C: International Monetary Fund.

Coady, David; Moataz El-Said, Robert Gillingham, Kangni Kpodar, Paulo Medas & David Newhouse (2006) The Magnitude and Distribution of Fuel Subsidies: Evidence from Bolivia, Ghana, Jordan, Mali, and Sri Lanka. *IMF Working Paper* 06(247). International Monetary Fund.

Coady, David; Ian Parry, Louis Sears & Baoping Shang (2015) How Large Are Global Energy Subsidies? *IMF Working Paper* 15(05). International Monetary Fund (https://www.imf.org/external/pubs/ft/wp/2015/wp15105.pdf).

Commander, Simon (2012) A Guide to the Political Economy of Reforming Energy Subsidies. *IZA Policy Paper* (52). Institute for the Study of Labour (http://ftp.iza.org/pp52.pdf).

Conibear, Luke; Edward W. Butt, Christoph Knote, Stephen R. Arnold & Dominick V. Spracklen (2018) Residential energy use emissions dominate health impacts from exposure to ambient particulate matter in India. *Nature communications* 9(1): 617.

Cooke, Edgar F.A.; Sarah Hague, Luca Tiberti, John Cockburn & Abdel-Rahmen El Lahga (2016) Estimating the impact on poverty of Ghana's fuel subsidy reform and a mitigating response. *Journal of Development Effectiveness* 8(1): 105–128.

CPI (Climate Policy Initiative) (2019) Global Landscape of Climate Finance 2019. [Buchner, Barbara; Clark, Alex; Falconer, Angela; Macquarie, Rob; Meattle, Chavi; Tolentino, Rowena; Wetherbee, Cooper]. *CPI Report*. London (https://climatepolicyinitiative.org/publication/ global-climate-finance-2019/).

Daniel M. Kammen (1995) Cookstoves for the Developing World. *Scientific American* 273(1): 72–75 (http://www.jstor.org/stable/24981454).

Dansie, Grant; Marc Lanteigne & Indra Overland (2010) Reducing Energy Subsidies in China, India and Russia: Dilemmas for Decision Makers. *Sustainability* 2(2): 475–493.

Dartanto, Teguh (2013) Reducing fuel subsidies and the implication on fiscal balance and poverty in Indonesia: A simulation analysis. *Energy Policy* 58: 117–134.

Davis, Lucas W. (2014) The Economic Cost of Global Fuel Subsidies. *American Economic Review* 104(5): 581–585.

Desai, Sonalde & Reeve Vanneman (2015) *India Human Development Survey-II (IHDS-II), 2011-12*. Inter-University Consortium for Political and Social Research.

DFID (United Kingdom Government Department for International Development) (2002) Energy for the poor: Underpinning the Millenium Development Goals. Department for International Development (https://www.iatp.org/sites/default/files/Energy_for_the_Poor_Underpinning_the_Millenniu.htm).

Díaz, Esperanza; Tone Smith-Sivertsen, Dan Pope, Rolv T. Lie, Anaite Díaz, John McCracken, Byron Arana, Kirk R. Smith & Nigel Bruce (2007) Eye discomfort, headache and back pain among Mayan Guatemalan women taking part in a randomised stove intervention trial. *Journal of epidemiology and community health* 61(1): 74–79.

Directorate of Census Operations Rajasthan (2014) Census of India 2011 Rajasthan: District Census Handbook Bikaner. Village and town wise primary census abstract (pca). *Series 09* (Part XII-B) (http://www.rajcensus.gov.in/).

Dreher, Axel; Jan-Egbert Sturm & James Raymond Vreeland (2009) Development aid and international politics: Does membership on the UN Security Council influence World Bank decisions? *Journal of Development Economics* 88(1): 1–18.

Drèze, Jean & Amartya Sen (2013) *An uncertain glory: India and its contradictions*. Princeton, New Jersey: Princeton University Press.

Dube, Ikhupuleng (2003) Impact of energy subsidies on energy consumption and supply in Zimbabwe. Do the urban poor really benefit? *Energy Policy* 31(15): 1635–1645.

Easterly, William (2007) Was Development Assistance a Mistake? *American Economic Review* 97(2): 328–332 (http://www.aeaweb.org/articles?id=10.1257/aer.97.2.328).

Eckholm, Erik (1975) *The other energy crisis: Firewood. Worldwatch paper* no. 1. Washington D.C.: Worldwatch Institute.

Edenhofer, Ottmar; Johannes Wallacher, Hermann Lotze-Campen, Michael Reder, Brigitte Knopf & Johannes Müller (eds) (2012) *Climate change, justice and sustainability: Linking climate and development policy*. Dordrecht: Springer.

Edwards, John & Christian Langpap (2005) Startup Costs and the Decision to Switch from Firewood to Gas Fuel. *Land Economics* 81(4): 570–586.

EIA (U.S. Energy Information Administration) (2016) International Energy Statistics (https://www.eia.gov/cfapps/ipdbproject/IEDIndex3.cfm?tid=2&pid=2&aid=12).

Ekouevi, Koffi (2013) Scaling Up Clean Cooking Solutions: The Context, Status, Barriers and Key Drivers. International Finance Corporation. Washington, D.C.: World Bank Group (http://documents1.worldbank.org/curated/en/750031490201011134/pdf/902780WP0Scali0vi0Box0385285B00OUO0.pdf).

Ekouevi, Koffi & Voravate Tuntivate (2012) *Household Energy Access for Cooking and Heating: Lessons Learned and the Way Forward*. Washington, D.C.: World Bank (https://openknowledge.worldbank.org/handle/10986/9372).

El Tayeb, Muneer Siddig & Mohamed El Waseilah Mukthar (2003) Adoption of biomass improved cookstoves in a patriarchal society: an example from Sudan. *The Science of The Total Environment* 307(1-3): 259–266.

El-Katiri, Laura & Bassam Fattouh (2017) A Brief Political Economy of Energy Subsidies in the Middle East and North Africa. *International Development Policy* 7(7): 1–27.

Ellis, Jennifer (2010) The Effects of Fossil-Fuel Subsidy Reform: A review of modelling and empirical studies. *Untold billions: fossil-fuel subsidies, their impacts and the path to reform*. International Institute for Sustainable Development (https://www.iisd.org/gsi/sites/default/files/effects_ffs.pdf).

European Investment Bank (2019) *EIB energy lending policy: Supporting the energy transformation* (https://www.eib.org/en/publications/eib-energy-lending-policy).

Evans, Peter & Barbara Stallings (2016) Development Studies: Enduring Debates and Possible Trajectories. *Studies in Comparative International Development* 51(1): 1–31 (https://link.springer.com/content/pdf/10.1007%2Fs12116-016-9223-9.pdf).

Ezzati, Majid & Jill C. Baumgartner (2017) Household energy and health: where next for research and practice? *The Lancet* 389(10065): 130–132.

Ezzati, Majid & Daniel M. Kammen (2001) Indoor air pollution from biomass combustion and acute respiratory infections in Kenya: an exposure-response study. *The Lancet* 358(9282): 619–624.

Ezzati, Majid & Daniel M. Kammen (2002) The health impacts of exposure to indoor air pollution from solid fuels in developing countries: knowledge, gaps, and data needs. *Environmental health perspectives* 110(11): 1057–1068.

Fall, Abdoulaye; Sécou Sarr, Touria Dafrallah & Abdou Ndour (2008) Modern energy access in peri-urban areas of West Africa: the case of Dakar, Senegal. *Energy for Sustainable Development* 12(4): 22–37.

Farsi, Mehdi; Massimo Filippini & Shonali Pachauri (2007) Fuel choices in urban Indian households. *Environment and Development Economics* 12(06).

Fay, Marianne; Stephane Hallegatte, Adrien Vogt-Schilb, Julie Rozenberg, Ulf Narloch & Tom Kerr (2015) *Decarbonizing Development: Three Steps to a Zero-Carbon Future: Climate Change and Development.* Washington, DC: World Bank (https://www.worldbank.org/content/dam/Worldbank/document/Climate/dd/decarbonizing-development-report.pdf).

Fernandez, Raquel & Dani Rodrik (1991) Resistance to Reform: Status Quo Bias in the Presence of Individual- Specific Uncertainty. *The American Economic Review* Vol. 81(5): 1146–1155 (http://www.jstor.org/stable/2006910).

Freedom House (2015) Freedom in the world: Aggregate and subcategory scores (https://freedomhouse.org/report/freedom-world-aggregate-and-subcategory-scores).

Freeman, Olivia E. & Hisham Zerriffi (2014) How you count carbon matters: implications of differing cookstove carbon credit methodologies for climate and development cobenefits. *Environmental science & technology* 48(24): 14112–14120.

G20 - Group of Twenty (2009) G20 Leaders' Declaration: The Pittsburgh Summit September 24-25, 2009 (https://www.fsb.org/wp-content/uploads/g20_leaders_declaration_pittsburgh_2009.pdf).

GACC (Global Alliance of Clean Cookstoves) (2017) Clean cooking: Key to achieving development and climate goals: 2016 progress report (http://cleancookstoves.org/resources/reports/2016progress.html).

Gan, Lin; Gunnar S. Eskeland & Hans H. Kolshus (2007) Green electricity market development: Lessons from Europe and the US. *Energy Policy* 35(1): 144–155.

Garland, Charity; Kirstie Jagoe, Emmy Wasirwa, Raphael Nguyen, Christa Roth, Ashwin Patel, Nisha Shah, Elisa Derby, John Mitchell, David Pennise & Michael A. Johnson (2015) Impacts of household energy programs on fuel consumption in Benin, Uganda, and India. *Energy for Sustainable Development* 27: 168–173.

GBD 2016 Risk Factors Collaborators (2017) Global, regional, and national comparative risk assessment of 84 behavioural, environmental and occupational, and metabolic risks or clusters of risks, 1990–2016: A systematic analysis for the Global Burden of Disease Study 2016. *The Lancet* 390(10100): 1345–1422.

GLPGP (The Global LPG Partnership) (2018) What We Do (http://glpgp.org/what-we-do/).

GOI (Government of India) (2012) *Revised Estimates of Annual National Income, 2011-12 and Quarterly Estimates of Gross Domestic Product, 2011-12*. New Delhi, India (http://pib.nic.in/newsite/PrintRelease.aspx?relid=84598).

GOI (Government of India) (2013-14) *Census of India 2011: Census Digital Library*. New Delhi, India (https://censusindia.gov.in/DigitalLibrary/Tables.aspx).

GOI (Government of India, Ministry of New and Renewable Energy) (2013) National Biomass Cookstoves Programme (NBCP) (http://pib.nic.in/newsite/printrelease.aspx?relid=94877).

Goldemberg, Jose; Javier Martinez-Gomez, Ambuj Sagar & Kirk R. Smith (2018) Household air pollution, health, and climate change: Cleaning the air. *Environmental Research Letters* 13(3).

Gould, Carlos F.; Samuel Schlesinger, Andres Ochoa Toasa, Mark Thurber, William F. Waters, Jay P. Graham & Darby W. Jack (2018) Government policy, clean fuel access, and persistent fuel stacking in Ecuador. *Energy for Sustainable Development* 46: 111–122.

Gould, Carlos F. & Johannes Urpelainen (2018) LPG as a clean cooking fuel: Adoption, use, and impact in rural India. *Energy Policy* 122: 395–408.

Government of Rajasthan (2017) Official Website of Rajasthan: About Bikaner, Statistical Handbook (http://bikaner.rajasthan.gov.in).

Grieshop, Andrew P.; Julian D. Marshall & Milind Kandlikar (2011) Health and climate benefits of cookstove replacement options. *Energy Policy* 39(12): 7530–7542.

Gupta, Gautam & Gunnar Köhlin (2006) Preferences for domestic fuel: Analysis with socio-economic factors and rankings in Kolkata, India. *Ecological Economics* 57(1): 107–121.

Gupta, Joyeeta (2009) Climate change and development cooperation: trends and questions. *Current Opinion in Environmental Sustainability* 1(2): 207–213.

Haffert, Lukas; Raphael Reinke & Tobias Rommel (2017) 'Nothing' is not a Control Group: On the Need for Placebo Comparisons in Survey Experiments. Presented at the annual conference of the Swiss Political Science Association January 2017.

Hamrick, Kelley & Melissa Gallant (2017) Unlocking Potential: State of the Voluntary Carbon Markets 2017. Forest Trends' Ecosystem Marketplace (https://www.cbd.int/financial/2017docs/carbonmarket2017.pdf).

Hamrick, Kelley & Allie Goldstein (2016) Raising Ambition: State of the Voluntary Carbon Markets 2016. Forest Trends' Marketplace (https://www.forest-trends.org/wp-content/uploads/2016/05/doc_5242.pdf).

Hanna, Rema; Esther Duflo & Michael Greenstone (2016) Up in Smoke: The Influence of Household Behavior on the Long-Run Impact of Improved Cooking Stoves. *American Economic Journal: Economic Policy* 8(1): 80–114.

Hanna, Rema & Paulina Oliva (2015) Moving up the Energy Ladder: The Effect of an Increase in Economic Well-Being on the Fuel Consumption Choices of the Poor in India. *American Economic Review* 105(5): 242–246.

Hansen, James & Larissa Nazarenko (2004) Soot climate forcing via snow and ice albedos. *Proceedings of the National Academy of Sciences of the United States of America* 101(2): 423–428.

Hay, Colin (2002) *Political analysis: A critical introduction. Political analysis Series*. London: Red Globe Press (http://www.loc.gov/catdir/description/hol031/2002020889.html).

Health Effects Institute (2019) State of Global Air 2019: Special Report. MA: Health Effects Institute. Boston (https://www.stateofglobalair.org/sites/default/files/soga_2019_report.pdf).

Heltberg, Rasmus (2004) Fuel switching: Evidence from eight developing countries. *Energy Economics* 26(5): 869–887.

Hosier, Richard H. & Jeffrey Dowd (1987) Household fuel choice in Zimbabwe: An Empirical Test of the Energy Ladder Hypothesis. *Ressources and Energy*: 347–361.

Hosonuma, Noriko; Martin Herold, Veronique de Sy, Ruth S. de Fries, Maria Brockhaus, Louis Verchot, Arild Angelsen & Erika Romijn (2012) An assessment of deforestation and forest degradation drivers in developing countries. *Environmental Research Letters* 7(4): 44009.

Hsu, Angel; Daniel C. Esty, Marc A. Levy & Alex de Sherbinin (2016) The 2016 Environmental Performance Index Report. New Haven, CT: Yale Center for Environmental Law and Policy (YCELP) (http://dx.doi.org/10.13140/RG.2.2.19868.90249).

Humphrey, Chris (2014) The politics of loan pricing in multilateral development banks. *Review of International Political Economy* 21(3): 611–639.

Hyman, Eric L. (1987) The strategy of production and distribution of improved charcoal stoves in Kenya. *World Development* 15(3): 375–386.

IEA (International Energy Agency) (1988) *Coal Prospects and Policies in IEA Countries: 1987 Review*. Paris: OECD and IEA.

IEA (International Energy Agency) (1999) *Looking at energy subsidies: Getting the prices right*. World Energy Outlook 1999 Insights. Paris: IEA.

IEA (International Energy Agency) (2011) *World Energy Outlook 2011*. Paris: IEA.

IEA (International Energy Agency) (2014) *World Energy Outlook 2014*. Paris: IEA (https://doi.org/10.1787/weo-2014-en).

IEA (International Energy Agency) (2015a) *Energy and Climate Change*. Paris: IEA (https://www.iea.org/reports/energy-and-climate-change).

IEA (International Energy Agency) (2015b) *World Energy Outlook 2015*. Paris: IEA (https://doi.org/10.1787/weo-2015-en).

IEA (International Energy Agency) (2016a) *Energy and Air Pollution: World Energy Outlook Special Report 2016*. Paris (https://www.iea.org/reports/energy-and-air-pollution).

IEA (International Energy Agency) (2016b) IEA World renewable and waste energy supply. IEA Renewables Information Statistics (database) (https://doi.org/10.1787/data-00550-en).

IEA (International Energy Agency) (2019a) Defining energy access: 2019 methodology (https://www.iea.org/articles/defining-energy-access-2019-methodology).

IEA (International Energy Agency) (2019b) *World Energy Outlook 2019*. Paris: IEA (https://www.iea.org/reports/world-energy-outlook-2019).

IEA (International Energy Agency) & IRENA (International Renewable Energy Agency) (2016) Global Renewable Energy: IEA/IRENA Joint Policies and Measures database (https://vipo.iea.org/policiesandmeasures/renewableenergy/).

IEA (International Energy Agency); IRENA (International Renewable Energy Agency), UN (United Nations), World Bank & WHO (World Health Organization) (2018) *Tracking SDG7: The Energy Progress Report 2018*. A joint report of the custodian agencies (https://openknowledge.worldbank.org/handle/10986/29812).

IEA (International Energy Agency); IRENA (International Renewable Energy Agency), UN (United Nations), World Bank & WHO (World Health Organization) (2019) *Tracking SDG7: The Energy Progress Report 2019*. A joint report of the custodian agencies (https://sustainabledevelopment.un.org/content/documents/2019_Tracking_SDG7_Report.pdf).

IEA (International Energy Agency); OECD (Organisation for Economic Co-operation and Development) & World Bank (2010) *The Scope of Fossil-Fuel Subsidies in 2009 and a Roadmap for Phasing Out Fossil-Fuel Subsidies: An IEA, OECD and World Bank Joint Report Prepared for the G-20 Summit, Seoul (Republic of Korea) 11-12 November 2010*.

IMF (International Monetary Fund) (2015) How Large are Global Energy Subsidies? Country-level Subsidy Estimates (database) (http://www.imf.org/external/np/fad/subsidies/data/codata.xlsx).

Independent Group of Scientists appointed by the Secretary-General (2019) Global Sustainable Development Report 2019: The Future is Now - Science for Achieving Sustainable Development. United Nations. New York (https://sustainabledevelopment.un.org/gsdr2019).

International Pathways to Clean Cooking conference (2019) *Wexford Declaration: Leaving no-one behind*. Wexford, Ireland. (http://www.pathways2cleancooking.info/).

ISO (International Organization for Standardization) (2019) Improving health with new standards for cleaner cookstoves (https://www.iso.org/news/ref2302.html).

Jack, Darby W.; Kwaku Poku Asante, Blair J. Wylie, Steve N. Chillrud, Robin M. Whyatt, Kenneth A. Ae-Ngibise, Ashlinn K. Quinn, Abena Konadu Yawson, Ellen Abrafi Boamah, Oscar Agyei, Mohammed Mujtaba, Seyram Kaali, Patrick Kinney & Seth Owusu-Agyei (2015) Ghana randomized air pollution and health study (GRAPHS): study protocol for a randomized controlled trial. *Trials* 16: 420.

Jain, Abhishek; Shalu Agrawal & Karthik Ganesan (2018) Lessons from the World's Largest Subsidy Benefit Transfer Scheme. In: Jakob Skovgaard & Harro Dirk van Asselt (eds) *The politics of fossil fuel subsidies and their reform*. Cambridge: Cambridge University Press, 212–228.

Jain, Abhishek; Sudatta Ray, Karthik Ganesan, Michaël Aklin, Chao-yo Cheng & Johannes Urpelainen (2015) *Access to Clean Cooking Energy and Electricity: Survey of States: Survey of States*. September. *CEEW Report*. New Delhi: Council on Energy, Environment and Water.

Jain, Abhishek; Saurabh Tripathi, Sunil Mani, Sasmita Patnaik, Tauseef Shahidi & Karthik Ganesan (2018) *Access to Clean Cooking Energy and Electricity: Survey of States 2018*. November. *CEEW Report*. New Delhi: Council on Energy, Environment and Water.

Jain, Amit & Zubair K. M. Sadeque (2017) Clean Cooking in Bangladesh: The experience from one million households (http://blogs.worldbank.org/energy/eastasiapacific/dmblog/clean-cooking-bangladesh-experience-one-million-households).

Jetter, James; Yongxin Zhao, Kirk R. Smith, Bernine Khan, Tiffany Yelverton, Peter Decarlo & Michael D. Hays (2012) Pollutant emissions and energy efficiency under controlled conditions for household biomass cookstoves and implications for metrics useful in setting international test standards. *Environmental science & technology* 46(19): 10827–10834.

Jin, Yinlong; Xiao Ma, Xining Chen, Yibin Cheng, Enis Baris & Majid Ezzati (2006) Exposure to indoor air pollution from household energy use in rural China: the interactions of technology, behavior, and knowledge in health risk management. *Social science & medicine (1982)* 62(12): 3161–3176.

Jones, Benjamin R.; Benjamin K. Sovacool & Roman V. Sidortsov (2015) Making the Ethical and Philosophical Case for "Energy Justice". *Environmental Ethics* 37(2): 145–168.

Joseph, S. (1983) *A preliminary evaluation of the impact of wood-burning stoves programmes*. Rome: Food and Agriculture Organization of the United Nations (FAO).

Kar, Abhishek; Shonali Pachauri, Rob Bailis & Hisham Zerriffi (2019) Using sales data to assess cooking gas adoption and the impact of India's Ujjwala programme in rural Karnataka. *Nature Energy* (https://doi.org/10.1038/s41560-019-0429-8).

Karlsson-Vinkhuyzen, Sylvia I. (2010) The United Nations and global energy governance: past challenges, future choices. *Global Change, Peace & Security* 22(2): 175–195.

Kaufmann, Daniel; Aart Kraay & Massimo Mastruzzi (2011) The Worldwide Governance Indicators: Methodology and Analytical Issues: Methodology and analytical issues. *Hague Journal on the Rule of Law* 3(02): 220–246.

Kees, Marlis & Lisa Feldmann (2011) The role of donor organisations in promoting energy efficient cook stoves. *Energy Policy* 39(12): 7595–7599.

Kettl, Donald F. (2009) Public Bureaucracies. In: Sarah A. Binder, R. A. W. Rhodes & Bert A. Rockman (eds) *The Oxford Handbook of Political Institutions*. Oxford University Press.

Khandelwal, Meena; Matthew E. Hill, Paul Greenough, Jerry Anthony, Misha Quill, Marc Linderman & H. S. Udaykumar (2017) Why Have Improved Cook-Stove Initiatives in India Failed? *World Development* 92: 13–27.

Khandker, Shahidur R.; Douglas F. Barnes & Hussain A. Samad (2013) Welfare Impacts of Rural Electrification: A Panel Data Analysis from Vietnam. *Economic Development and Cultural Change* 61(3): 659–692.

Kilby, Christopher (2006) Donor influence in multilateral development banks: The case of the Asian Development Bank. *The Review of International Organizations* 1(2): 173–195.

Kilby, Christopher & Axel Dreher (2010) The impact of aid on growth revisited: Do donor motives matter? *Economics Letters* 107(3): 338–340.

Kishore, Vallentyne V. N. & P. Venkata Ramana (2002) Improved cookstoves in rural India: how improved are they? *Energy* 27(1): 47–63.

Kitson, Lucy & Richard Bridle (2014) The Impact of Fossil-Fuel Subsidies on Renewable Electricity Generation. *GSI Report*. International Institute for Sustainable Development December 2014 (https://www.iisd.org/publications/impact-fossil-fuel-subsidies-renewable-electricity-generation).

Kojima, Masami (2011) The Role of Liquefied Petroleum Gas in Reducing Energy Poverty. *Extractive industries for development series* (25). Washington, D.C: World Bank Group (http://documents.worldbank.org/curated/en/390661468157779954/The-role-of-liquefied-petroleum-gas-in-reducing-energy-poverty).

Koplow, Doug (2018) Defining and Measuring Fossil Fuel Subsidies. In: Jakob Skovgaard & Harro van Asselt (eds) *The Politics of Fossil Fuel Subsidies and their Reform*. Cambridge University Press, 23–46.

Kosmo, Mark (1987) *Money to burn? The high costs of energy subsidies*. Washington D.C.: World Resources Institute.

Krishnapriya, P. P. (2017) *Effects of information on energy related choices: Experimental evidence from rural Uttar Pradesh and Kerala*. Preliminary Draft (https://www.isid.ac.in/~epu/acegd2016/papers/PPKrishnapriya.pdf).

Krugmann, Hartmut (1987) Review of Issues and Research Relating to Improved Cookstoves. *Manuscript Report* (152e). International Development Research Center.

Kshirsagar, Milind P. & Vilas R. Kalamkar (2014) A comprehensive review on biomass cookstoves and a systematic approach for modern cookstove design. *Renewable and Sustainable Energy Reviews* 30: 580–603.

Lan, Qing; Robert S. Chapman, Dina M. Schreinemachers, Linwei Tian & Xingzhou He (2002) Household stove improvement and risk of lung cancer in Xuanwei, China. *Journal of the National Cancer Institute* 94(11): 826–835.

Larsen, Bjorn & Anwar Shah (1992) *World Fossil Fuel Subsidies and Global Carbon Emissions: Background paper for World Development Report 1992. Policy Research Working Paper (WPS)* no. 1002. Washington D.C.: World Bank.

Leach, Gerald (1992) The energy transition. *Energy Policy* 20(2): 116–123.

Leach, Gerald & Robin Mearns (1988) *Beyond the woodfuel crisis: People, land, and trees in Africa. Earthscan library collection* volume 2. London: Earthscan Publications.

Lee, A; D Jack, S Owusu-Agyei, B Wylie, S N Chillrud, R Whyatt, K Ae-Ngibise, A Quinn, A Yawson, E Boamah, O Agyei, R Tokarz, S Kaali, P L Kinney & K P Asante (2017) Clean Cookstove Household Air Pollution Intervention Decreases The Risk For Bacterial Pneumonia But Not Viral Pneumonia: American Thoracic Society 2017 International Conference Abstract. *American Journal of Respiratory and Critical Care Medicine* (195): A5976.

Lee, Carrie M.; Chelsea Chandler, Michael Lazarus & Francis X. Johnson (2014) Assessing the Climate Impacts of Cookstove Projects: Issues in Emissions Accounting. *Challenges in Sustainability* 1(2).

Leftwich, Adrian & Kunal Sen (2011) "Don't mourn; organize" institutions and organizations in the politics and economics of growth and poverty-reduction. *Journal of International Development* 23(3): 319–337 (https://onlinelibrary.wiley.com/doi/pdf/10.1002/jid.1773).

Lehmann, Ina (2019) When cultural political economy meets 'charismatic carbon' marketing: A gender-sensitive view on the limitations of Gold Standard cookstove offset projects. *Energy Research & Social Science* 55: 146–154.

Levine, David I.; Theresa Beltramo, Garrick Blalock, Carolyn Cotterman & Andrew M. Simons (2018) What Impedes Efficient Adoption of Products? Evidence from Randomized Sales Offers for Fuel-Efficient Cookstoves in Uganda. *Journal of the European Economic Association* 16(6): 1850–1880.

Lewis, Jessica J. & Subhrendu K. Pattanayak (2012) Who adopts improved fuels and cookstoves? A systematic review. *Environmental health perspectives* 120(5): 637–645.

Lockwood, Matthew (2014) Fossil Fuel Subsidy Reform, Rent Management and Political Fragmentation in Developing Countries. *New Political Economy*: 1–20.

Lucon, Oswaldo; Suani Teixeira Coelho & José Goldemberg (2004) LPG in Brazil: lessons and challenges. *Energy for Sustainable Development* 8(3): 82–90.

Ma, Jieru; Tinghan Zhang, Xiaodan Guan, Xiaoming Hu, Anmin Duan & Jingchen Liu (2019) The Dominant Role of Snow/Ice Albedo Feedback Strengthened by Black Carbon in the Enhanced Warming over the Himalayas. *Journal of Climate* 32(18): 5883–5899.

MacCarty, Nordica; Dean Still & Damon Ogle (2010) Fuel use and emissions performance of fifty cooking stoves in the laboratory and related benchmarks of performance. *Energy for Sustainable Development* 14(3): 161–171.

Manibog, Fernando R. (1984) Improved Cooking Stoves in Developing Countries: Problems and Opportunities. *Annual Review of Energy* 9(1): 199–227.

Manning, Dale T. & J. Edward Taylor (2014) Migration and fuel use in rural Mexico. *Ecological Economics* 102: 126–136.

Marques, António C.; José A. Fuinhas & J. R. Pires Manso (2010) Motivations driving renewable energy in European countries: A panel data approach. *Energy Policy* 38(11): 6877–6885.

Masera, Omar R.; Rob Bailis, Rudi Drigo, Adrian Ghilardi & Ilse Ruiz-Mercado (2015) Environmental Burden of Traditional Bioenergy Use. *Annual Review of Environment and Resources* 40(1): 121–150.

Masera, Omar R.; Rodolfo Díaz & Víctor Berrueta (2005) From cookstoves to cooking systems: the integrated program on sustainable household energy use in Mexico. *Energy for Sustainable Development* 9(1): 25–36.

Masera, Omar R.; Barbara D. Saatkamp & Daniel M. Kammen (2000) From Linear Fuel Switching to Multiple Cooking Strategies: A Critique and Alternative to the Energy Ladder Model. *World Development* 28(12): 2083–2103.

Matsuo, Tyeler & Tobias S. Schmidt (2017) Hybridizing low-carbon technology deployment policy and fossil fuel subsidy reform: a climate finance perspective. *Environmental Research Letters* 12(1): 14002.

Maynard, Robert; Michal Krzyzanowski, Nadia Vilahur & Marie-Eve Héroux (2017) *Evolution of WHO air quality guidelines: Past, present and future*. Copenhagen: WHO Regional Office for Europe.

Mc Lure Jr., Charles E. (2014) Reforming subsidies for fossil fuel consumption: Killing several birds with one stone. In: Richard M. Bird & Jorge Martinez-Vazquez (eds) *Taxation and*

Development: The Weakest Link? Essays in Honor of Roy Bahl. Studies in fiscal federalism and state-local finance. Cheltenham, UK: Edward Elgar, 238–283.

McCulloch, Neil (2017) Energy subsidies, international aid, and the politics of reform. *WIDER Working Paper* 2017(174). UNU-WIDER 2017 (https://doi.org/10.35188/UNU-WIDER/).

McDade, Susan (2004) Fueling development: the role of LPG in poverty reduction and growth. *Energy for Sustainable Development* 8(3): 74–81.

Meier, Peter; Maria Vagliasindi & Mudassar Imran (2015) *The Design and Sustainability of Renewable Energy Incentives: An Economic Analysis*. Directions in Development. Washington D.C.: World Bank.

Menghwani, Vikas; Hisham Zerriffi, Puneet Dwivedi, Julian D. Marshall, Andrew Grieshop & Rob Bailis (2019) Determinants of Cookstoves and Fuel Choice Among Rural Households in India. *EcoHealth* 16(1): 21–60.

Michaelowa, Axel & Katharina Michaelowa (2007) Climate or development: is ODA diverted from its original purpose? *Climatic Change* 84(1): 5–21.

Michaelowa, Axel & Katharina Michaelowa (2011) Coding Error or Statistical Embellishment? The Political Economy of Reporting Climate Aid. *World Development* 39(11): 2010–2020.

Miller, Grant & A. Mushfiq Mobarak (2015) Learning About New Technologies Through Social Networks: Experimental Evidence on Nontraditional Stoves in Bangladesh. *Marketing Science* 34(4): 480–499.

Mobarak, Ahmed Mushfiq; Puneet Dwivedi, Robert Bailis, Lynn Hildemann & Grant Miller (2012) Low demand for nontraditional cookstove technologies. *Proceedings of the National Academy of Sciences of the United States of America* 109(27): 10815–10820.

Montgomery, W. David (1972) Markets in licenses and efficient pollution control programs. *Journal of Economic Theory* 5(3): 395–418.

Morrison, Sara (2018) Undercooked: An expensive push to save lives and protect the planet falls short. *Pro Publica* 12 July (https://www.propublica.org/article/cookstoves-push-to-protect-the-planet-falls-short).

Mortimer, Kevin; Chifundo B. Ndamala, Andrew W. Naunje, Jullita Malava, Cynthia Katundu, William Weston, Deborah Havens, Daniel Pope, Nigel G. Bruce, Moffat Nyirenda, Duolao Wang, Amelia Crampin, Jonathan Grigg, John Balmes & Stephen B. Gordon (2017) A cleaner burning biomass-fuelled cookstove intervention to prevent pneumonia in children under 5 years old in rural Malawi (the Cooking and Pneumonia Study): a cluster randomised controlled trial. *The Lancet* 389(10065): 167–175.

Mueller, Dennis C. (2003) *Public Choice III*. Cambridge: Cambridge University Press.

Muller, Christophe & Huijie Yan (2018) Household fuel use in developing countries: Review of theory and evidence: Review of Theory and Evidence. *Energy Economics* 70(13): 429–439.

Mundlak, Yair (1978) On the Pooling of Time Series and Cross Section Data. *Econometrica* 46(1): 69.

Muralidharan, Veena; Thomas E. Sussan, Sneha Limaye, Kirsten Koehler, D'Ann L. Williams, Ana M. Rule, Sanjay Juvekar, Patrick N. Breysse, Sundeep Salvi & Shyam Biswal (2015) Field testing of alternative cookstove performance in a rural setting of western India. *International journal of environmental research and public health* 12(2): 1773–1787.

Najam, Adil & Cutler J Cleveland (2003) Energy and Sustainable Development at Global Environmental Summits: An Evolving Agenda. *Environment, Development and Sustainability* (5): 117–138.

Nepal, Mani; Apsara Nepal & Kristine Grimsrud (2011) Unbelievable but improved cookstoves are not helpful in reducing firewood demand in Nepal. *Environment and Development Economics* 16(01): 1–23.

Newell, Peter & Phil Johnstone (2018) The Political Economy of Incumbency. In: Jakob Skovgaard & Harro Dirk van Asselt (eds) *The politics of fossil fuel subsidies and their reform*. Cambridge: Cambridge University Press, 66–80.

Nordhaus, William D. (1977) Economic Growth and Climate: The Carbon Dioxide Problem. *American Economic Review* 67(1): 341–346 (http://www.jstor.org/stable/1815926).

North, Douglass C. (1990) *Institutions, Institutional Change and Economic Performance (Political Economy of Institutions and Decisions)*. Cambridge: Cambridge University Press.

Nwankwo, Ogonna N. O.; Ndubuisi Mokogwu, Orighomisan Agboghoroma, Fahmi O. Ahmed & Kevin Mortimer (2018) Knowledge, attitudes and beliefs about the health hazards of biomass smoke exposure amongst commercial food vendors in Nigeria. *PloS one* 13(1): e0191458.

OECD (2007) Subsidy reform and sustainable development: Political economy aspects. Proceedings of an OECD Workshop on 'Subsidy Reform and Sustainable Development: Political Economy Aspects' held in Helsinki, Finland on 20 - 21 June 2006. *OECD sustainable development studies*. Paris: OECD.

OECD (2013) Inventory of Estimated Budgetary Support and Tax Expenditures for Fossil Fuels 2013. Paris: OECD Publishing (https://doi.org/10.1787/9789264187610-en).

OECD (2018) OECD Companion to the Inventory of Support Measures for Fossil Fuels 2018. Paris: OECD Publishing (https://doi.org/10.1787/9789264286061-en).

OECD (2019) *Climate Finance Provided and Mobilised by Developed Countries in 2013-17*. Paris: OECD Publishing (https://www.oecd-ilibrary.org/content/publication/39faf4a7-en).

O'Sullivan, Kyran & Douglas F. Barnes (2006) Energy Policies and Multitopic Household Surveys: Guidelines for Questionnaire Design in Living Standards Measurement Studies. *World bank working paper* (90). Energy Sector Management Assistance Program. Washington, D.C.: The World Bank (https://elibrary.worldbank.org/doi/abs/10.1596/978-0-8213-6878-7).

Peterson, Lauri & Jakob Skovgaard (2019) Bureaucratic politics and the allocation of climate finance. *World Development* 117: 72–97.

Pickering, Jonathan; Jakob Skovgaard, Soyeun Kim, J. Timmons Roberts, David Rossati, Martin Stadelmann & Hendrikje Reich (2015) Acting on Climate Finance Pledges: Inter-

Agency Dynamics and Relationships with Aid in Contributor States. *World Development* 68: 149–162.

Pigou, Arthur Cecil (1920) *The Economics of Welfare*. London: Macmillan.

Plante, Michael (2014) The long-run macroeconomic impacts of fuel subsidies. *Journal of Development Economics* 107: 129–143.

Pollard, Suzanne L.; Kendra N. Williams, Carolyn J. O'Brien, Abigail Winiker, Elisa Puzzolo, Josiah L. Kephart, Magdalena Fandiño-Del-Rio, Carla Tarazona-Meza, Matthew R. Grigsby, Marilú Chiang & William Checkley (2018) An evaluation of the Fondo de Inclusión Social Energético program to promote access to liquefied petroleum gas in Peru. *Energy for Sustainable Development* 46: 82–93.

Pope, Daniel; Nigel G. Bruce, Mukesh Dherani, Kirstie Jagoe & Eva Rehfuess (2017) Real-life effectiveness of 'improved' stoves and clean fuels in reducing PM2.5 and CO: Systematic review and meta-analysis. *Environment international* 101: 7–18.

Popp, David; Ivan Hascic & Neelakshi Medhi (2011) Technology and the diffusion of renewable energy. *Energy Economics* 33(4): 648–662.

Putti, Venkata Ramana; Michael Tsan, Sumi Mehta & Srilata Kammila (2015) The state of the global clean and improved cooking sector. *ESMAP Technical Paper* (15/007). Washington D.C.: World Bank (https://openknowledge.worldbank.org/handle/10986/21878).

Puzzolo, Elisa; Daniel Pope, Debbi Stanistreet, Eva A. Rehfuess & Nigel G. Bruce (2016) Clean fuels for resource-poor settings: A systematic review of barriers and enablers to adoption and sustained use. *Environmental research* 146: 218–234.

Quansah, Reginald; Sean Semple, Caroline A. Ochieng, Sanjar Juvekar, Frederick Ato Armah, Isaac Luginaah & Jacques Emina (2017) Effectiveness of interventions to reduce household air pollution and/or improve health in homes using solid fuel in low-and-middle income countries: A systematic review and meta-analysis. *Environment international* 103: 73–90.

Quinn, Ashlinn K.; Nigel G. Bruce, Elisa Puzzolo, Katherine Dickinson, Rachel Sturke, Darby W. Jack, Sumi Mehta, Anita Shankar, Kenneth Sherr & Joshua P. Rosenthal (2018) An analysis of efforts to scale up clean household energy for cooking around the world. *Energy for Sustainable Development* 46: 1–10.

Rao, Narasimha D. (2012) Kerosene subsidies in India: When energy policy fails as social policy. *Energy for Sustainable Development* 16(1): 35–43.

Rehfuess, Eva A.; Elisa Puzzolo, Debbi Stanistreet, Daniel Pope & Nigel G. Bruce (2014) Enablers and barriers to large-scale uptake of improved solid fuel stoves: a systematic review. *Environmental health perspectives* 122(2): 120–130.

REN21 (RENEWABLE ENERGY POLICY NETWORK FOR THE 21st CENTURY) (2015) Renewables 2015 Global Status Report (http://www.ren21.net/status-of-renewables/global-status-report/).

Rentschler, Jun & Morgan Bazilian (2017) Reforming fossil fuel subsidies: drivers, barriers and the state of progress. *Climate Policy* 17(7): 891–914.

Rhee, Michelle; Mahamadou Sissoko, Sharon Perry, Willi McFarland, Julie Parsonnet & Ogobara Doumbo (2005) Use of insecticide-treated nets (ITNs) following a malaria education intervention in Piron, Mali: a control trial with systematic allocation of households. *Malaria journal* 4: 35.

Rosenbaum, Julia; Elisa Derby & Karabi Dutta (2015) Understanding consumer preference and willingness to pay for improved cookstoves in Bangladesh. *Journal of health communication* 20 Suppl 1: 20–27.

Rosenthal, Joshua; Ashlinn Quinn, Andrew P. Grieshop, Ajay Pillarisetti & Roger I. Glass (2018) Clean cooking and the SDGs: Integrated analytical approaches to guide energy interventions for health and environment goals. *Energy for sustainable development : the journal of the International Energy Initiative* 42: 152–159.

Ross, Michael L.; Chad Hazlett & Paasha Mahdavi (2017) Global progress and backsliding on gasoline taxes and subsidies. *Nature Energy* 2(1): 16201.

Ruiz-Mercado, Ilse & Omar Masera (2015) Patterns of stove use in the context of fuel-device stacking: rationale and implications. *EcoHealth* 12(1): 42–56.

Ruiz-Mercado, Ilse; Omar Masera, Hilda Zamora & Kirk R. Smith (2011) Adoption and sustained use of improved cookstoves. *Energy Policy* 39(12): 7557–7566.

Sadorsky, Perry (2009a) Renewable energy consumption and income in emerging economies. *Energy Policy* 37(10): 4021–4028.

Sadorsky, Perry (2009b) Renewable energy consumption, CO2 emissions and oil prices in the G7 countries. *Energy Economics* 31(3): 456–462.

Sagar, Ambuj D. (2005) Alleviating energy poverty for the world's poor. *Energy Policy* 33(11): 1367–1372.

Sand, Maria; Terje K. Berntsen, Knut von Salzen, Marc G. Flanner, Joachim Langner & David G. Victor (2016) Response of Arctic temperature to changes in emissions of short-lived climate forcers. *Nature Climate Change* 6(3): 286–289.

Sand, Maria; Terje K. Berntsen, Øyvind Seland & Jón E. Kristjánsson (2013) Arctic surface temperature change to emissions of black carbon within Arctic or midlatitudes. *Journal of Geophysical Research: Atmospheres* 118(14): 7788–7798.

Schauer, James J.; Michael J. Kleeman, Glen R. Cass & Bernd R. T. Simoneit (2001) Measurement of Emissions from Air Pollution Sources. 3. C 1 −C 29 Organic Compounds from Fireplace Combustion of Wood. *Environmental Science & Technology* 35(9): 1716–1728.

Schmidt, Tobias S.; Robin Born & Malte Schneider (2012) Assessing the costs of photovoltaic and wind power in six developing countries. *Nature Climate Change* 2(7): 548–553.

Schmidt, Vivien A. (2008) Discursive Institutionalism: The Explanatory Power of Ideas and Discourse. *Annual Review of Political Science* 11(1): 303–326.

Schunck, Reinhard (2013) Within and between estimates in random-effects models: Advantages and drawbacks of correlated random effects and hybrid models. *The Stata Journal* 13(1): 65–76.

Schunck, Reinhard & Francisco Perales (2017) Within- and Between-cluster Effects in Generalized Linear Mixed Models: A Discussion of Approaches and the Xthybrid command. *The Stata Journal* 17(1): 89–115.

SEforALL (Sustainable Energy for All) (2018) Country Actions: Action Agenda. Sustainable Energy for All Africa Hub (https://www.se4all-africa.org/seforall-in-africa/country-actions/action-agenda/).

SEforALL (Sustainable Energy for All) & CPI (Climate Policy Initiative) (2018) Energizing Finance: Understanding the Landscape 2018. *Energizing Finance Report Series*. Sustainable Energy for All (SEforALL.org/EnergizingFinance).

SEforALL (Sustainable Energy for All) & CPI (Climate Policy Initiative) (2019) Energizing Finance: Understanding the Landscape 2019. *Energizing Finance Report Series* (SEforALL.org/EnergizingFinance).

Segal, Paul (2012) How to spend it: Resource wealth and the distribution of resource rents. *Energy Policy* 51: 340–348.

Serrano-Medrano, M.; C. García-Bustamante, V. M. Berrueta, R. Martínez-Bravo, V. M. Ruiz-García, A. Ghilardi & O. Masera (2018) Promoting LPG, clean woodburning cookstoves or both? Climate change mitigation implications of integrated household energy transition scenarios in rural Mexico. *Environmental Research Letters* 13(11): 115004.

Seto, Karen C.; Steven J. Davis, Ronald B. Mitchell, Eleanor C. Stokes, Gregory Unruh & Diana Ürge-Vorsatz (2016) Carbon Lock-In: Types, Causes, and Policy Implications. *Annual Review of Environment and Resources* 41(1): 425–452.

Shang, Baoping; Le Nghia-Piotr, Ian Parry & David Coady (2019) Global Fossil Fuel Subsidies Remain Large: An Update Based on Country-Level Estimates. *IMF Working Paper* 19(89). International Monetary Fund.

Shen, Guofeng; Michael D. Hays, Kirk R. Smith, Craig Williams, Jerroll W. Faircloth & James J. Jetter (2018) Evaluating the Performance of Household Liquefied Petroleum Gas Cookstoves. *Environmental science & technology* 52(2): 904–915.

Shen, Min; Robert S. Chapman, Roel Vermeulen, Linwei Tian, Tongzhang Zheng, Bingshu E. Chen, Eric A. Engels, Xingzhou He, Aaron Blair & Qing Lan (2009) Coal use, stove improvement, and adult pneumonia mortality in Xuanwei, China: a retrospective cohort study. *Environmental health perspectives* 117(2): 261–266.

Singh, D.; S. Pachauri & H. Zerriffi (2017) Environmental payoffs of LPG cooking in India. *Environmental Research Letters* 12(11): 115003.

Sinton, Jonathan E.; Kirk R. Smith, John W. Peabody, Liu Yaping, Zhang Xiliang, Rufus Edwards & Gan Quan (2004) An assessment of programs to promote improved household stoves in China. *Energy for Sustainable Development* 8(3): 33–52.

Skovgaard, Jakob & Harro van Asselt (2019) The politics of fossil fuel subsidies and their reform: Implications for climate change mitigation. *Wiley Interdisciplinary Reviews: Climate Change* 12(1): e581.

Smith, Kirk R. (1987) *Biofuels, air pollution, and health: A global review. Modern perspectives in energy*. New York: Plenum Press.

Smith, Kirk R. (1993) Fuel Combustion, Air Pollution Exposure, and Health: The Situation in Developing Countries. *Annual Review of Energy and the Environment* 18(1): 529–566.

Smith, Kirk R. (2002) In praise of petroleum? *Science* 298(5600): 1847.

Smith, Kirk R. & Evan Haigler (2008) Co-benefits of climate mitigation and health protection in energy systems: scoping methods. *Annual review of public health* 29: 11–25.

Smith, Kirk R.; John P. McCracken, Martin W. Weber, Alan Hubbard, Alisa Jenny, Lisa M. Thompson, John Balmes, Anaité Diaz, Byron Arana & Nigel G. Bruce (2011) Effect of reduction in household air pollution on childhood pneumonia in Guatemala (RESPIRE): a randomised controlled trial. *The Lancet* 378(9804): 1717–1726.

Smith, Kirk R. & Ambuj Sagar (2014) Making the clean available: Escaping India's Chulha Trap. *Energy Policy* 75: 410–414.

Smith, Kirk R.; Gu Shuhua, Huang Kun & Qiu Daxiong (1993) One hundred million improved cookstoves in China: How was it done? *World Development* 21(6): 941–961.

Smith, Kirk R.; R. Uma, V. V.N. Kishore, Junfeng Zhang, V. Joshi & M. A.K. Khalil (2000) Greenhouse Implications of Household Stoves: An Analysis for India. *Annual Review of Energy and the Environment* (25): 741–763.

Smith-Sivertsen, Tone; Esperanza Díaz, Nigel G. Bruce, Anaité Diaz, Asheena Khalakdina, A. Morton Schei, John McCracken, Byron Arana, Robert Klein, Lisa Thompson & Kirk R. Smith (2004) Reducing indoor air pollution with a randomised intervention design – A presentation of the Stove Intervention Study in the Guatemalan Highlands. *Norsk Epidemiologi* 14(2): 137–143.

Sovacool, Benjamin K. (2014) Defining, Measuring, and Tackling Energy Poverty. In: Antoine Halff, Benjamin K. Sovacool & Jon Rozhon (eds) *Energy poverty: Global challenges and local solutions*. Oxford: Oxford University Press, 21–53.

Sovacool, Benjamin K.; Raphael J. Heffron, Darren McCauley & Andreas Goldthau (2016) Energy decisions reframed as justice and ethical concerns. *Nature Energy* 1: 16024.

Spalding-Fecher, Randall; Harald Winkler & Stanford Mwakasonda (2005) Energy and the World Summit on Sustainable Development: what next? *Energy Policy* 33(1): 99–112.

Stadelmann, Martin & Paula Castro (2014) Climate policy innovation in the South – Domestic and international determinants of renewable energy policies in developing and emerging countries. *Global Environmental Change* 29: 413–423.

Stadelmann, Martin; J. Timmons Roberts & Axel Michaelowa (2011) New and additional to what? Assessing options for baselines to assess climate finance pledges. *Climate and Development* 3(3): 175–192.

Stefanski, Radoslaw (2014) Dirty Little Secrets: Inferring Fossil-Fuel Subsidies from Patterns in Emission Intensities. *OxCarre Working Papers* (134). Oxford Centre for the Analysis of Resource Rich Economies, University of Oxford.

Tara Shine & Gisela Campillo (2016) *The Role of Development Finance in Climate Action Post-2015. OECD Development Co-operation Working Papers* no. 31. Paris: OECD Publishing (https://www.oecd-ilibrary.org/content/paper/18a859bf-en).

Teorell, Jan; Stefan Dahlberg, Sören Holmberg, Bo Rothstein, Anna Khomenko & Richard Svensson (2016) QoG Standard Dataset 2016, version Jan16 (http://www.qog.pol.gu.se doi:10.18157/QoGStdJan16).

Terton, Anika; Philip Gass, Laura Merrill, Armin Wagner & Eike Meyer (2015) Fiscal Instruments in INDCs: How countries are looking to fiscal policies to support INDC implementation. *IISD discussion paper*. International Institute for Sustainable Development. Geneva.

The Gold Standard (2015) *Technologies and Practices to Displace Decentralized Thermal Energy Consumption: Version 2.0* (https://www.goldstandard.org/sites/default/files/revised-tpddtec-methodology_april-2015_final-clean.pdf).

The Gold Standard (2016) *Gold Standard Improved Cookstoves Methodologies Guidebook: GS Simplified, AMS II.G and TPDDTEC Version 1.0* (http://www.goldstandard.org/sites/default/files/documents/ics_methodology_guidebook_v1.pdf).

The Guardian (2016) Slump in oil prices drives green energy takeup in top exporting nations 20 January (http://www.theguardian.com/environment/2016/jan/20/slump-in-oil-prices-drives-green-energy-take-up-in-top-exporting-nations).

Thoday, Katharine; Precious Benjamin, Meixi Gan & Elisa Puzzolo (2018) The Mega Conversion Program from kerosene to LPG in Indonesia: Lessons learned and recommendations for future clean cooking energy expansion. *Energy for Sustainable Development* 46: 71–81.

Thomas, Emma; Kremlin Wickramasinghe, Shanthi Mendis, Nia Roberts & Charlie Foster (2015) Improved stove interventions to reduce household air pollution in low and middle income countries: a descriptive systematic review. *BMC public health* 15: 650.

Thorbecke, Erik (2008) The Evolution of the Development Doctrine, 1950–2005. In: George Mavrotas (ed.) *Advancing development: Core themes in global economics*. Studies in development economics and policy. Basingstoke: Palgrave Macmillan, 3–36.

Troncoso, Karin; Alicia Castillo, Omar Masera & Leticia Merino (2007) Social perceptions about a technological innovation for fuelwood cooking: Case study in rural Mexico. *Energy Policy* 35(5): 2799–2810.

Troncoso, Karin & Agnes Soares da Silva (2017) LPG fuel subsidies in Latin America and the use of solid fuels to cook. *Energy Policy* 107: 188–196 (http://dx.doi.org/10.1016/j.enpol.2017.04.046).

Tun, Khin Myat; Han Win, T Ohnmar, Aung Kyaw Zaw, Thuzar Myint, Khin Khin Swe Myat, Sandar Kyi & Than Than Lwin (2005) Indoor Air Pollution: Impact of Intervention on Acute Respiratory Infection (ARI) in Under-five Children. *Regional Health Forum* 9(1): 30–36.

U.S. National Library of Medicine (2016) Household Air Pollution and Health: A Multi-country LPG Intervention Trial (https://clinicaltrials.gov/ct2/show/NCT02944682).

UN Commission on Sustainable Development (2001) Report on the Ninth Session (May 5, 2000 and April 16-27, 2001). E/CN.17/2001/19. *Economic and Social Council, Official Records* (Supplement No. 9). United Nations. New York (http://www.un.org/documents/ecosoc/docs/2001/e2001-29.pdf).

UN Millennium Project (2005) *Investing in development: A practical plan to achieve the Millennium Development Goals*. New York (http://www.unmillenniumproject.org/reports/fullreport.htm).

UNDP (United Nations Development Programme) & WHO (World Health Organisation) (2009) The Energy Access Situation in Developing Countries: A Review Focusing on the Least Developed Countries and Sub-Saharan Africa. United Nations Development Programme.

UNEP-IMF-GIZ-GSI Workshop (2014) Reforming Fossil Fuel Subsidies for an Inclusive Green Economy: Summary Report. Nairobi, Kenya April 2014.

UNFCCC (United Nations Framework Convention on Climate Change) (2007) *Fossil fuel efficiency projects to receive much-needed investment under Kyoto Protocol's clean development mechanism*. Press release, 14 September 2007. Bonn.

UNFCCC (United Nations Framework Convention on Climate Change) (2014) Carbon finance fueling shift to clean cookstoves. Report (https://unfccc.int/news/carbon-finance-fueling-shift-to-clean-cookstoves).

UNFCCC (United Nations Framework Convention on Climate Change) (2017a) Concept note: Analysis of eligibility of shift from NRB to LPG under AMS-I.E. and AMS-II.G. Clean Development Mechanism Small Scale Working Group 54, Annex 2 (Version 01.0) August 2017 (http://cdm.unfccc.int/Panels/ssc_wg/index.html).

UNFCCC (United Nations Framework Convention on Climate Change) (2017b) Clean Development Mechanism: CDM Methodology Booklet. Information updated as of EB 97 (Ninth edition). United Nations Framework Convention on Climate Change November 2017 (https://cdm.unfccc.int/methodologies/documentation/meth_booklet.pdf).

UNFCCC (United Nations Framework Convention on Climate Change) (2020) NDC Registry (interim) (https://www4.unfccc.int/sites/NDCStaging/Pages/All.aspx).

UN (United Nations) (1992) *United Nations Conference on Environment and Development, Rio de Janeiro, June 3-14, 1992: Agenda 21*. Rio de Janeiro (https://sustainabledevelopment.un.org/content/documents/Agenda21.pdf).

UN (United Nations) (2000) United Nations Millennium Declaration: 8th plenary meeting, 8 September 2000. Resolution adopted by the General Assembly (A/RES/55/2). United Nations. New York (http://www.un.org/millennium/declaration/ares552e.htm).

UN (United Nations) (2001) Road map towards the implementation of the United Nations Millenium Declaration: Fifty-sixth session. 6 September 2001. Follow-up to the outcome of the Millennium Summit. Report of the Secretary-General (A/56/326). United Nations. New York (http://www.un.org/en/ga/search/view_doc.asp?symbol=A/56/326).

UN (United Nations) (2011) International Year of Sustainable Energy for All: 69th plenary meeting, 20 December 2010. Resolution adopted by the General Assembly (A/RES/65/151). United Nations. New York.

UN (United Nations) (2012) The future we want: Sixty-sixth session, 27 July 2012. Resolution adopted by the General Assembly (A/RES/66/288). United Nations. New York.

UN (United Nations) (2015) Transforming Our World: The 2030 Agenda for Sustainable Development. Resolution adopted by the General Assembly on 25 September 2015, A/RES/70/1. United Nations. New York.

UN (United Nations) (2019) The Sustainable Development Goals report 2019. New York: United Nations.

UN (United Nations Department of Economic and Social Affairs, Sustainable Development) (2020) Goal 7 Ensure access to affordable, reliable, sustainable and modern energy for all. Targets and Indicators (https://sdgs.un.org/goals/goal7).

Urmee, Tania & Samuel Gyamfi (2014) A review of improved Cookstove technologies and programs. *Renewable and Sustainable Energy Reviews* 33: 625–635.

Vagliasindi, Maria (2013) *Implementing energy subsidy reforms: Evidence from developing countries. Directions in development. Energy and mining*. Washington, D.C.: World Bank.

van de Graaf, Thijs & Mathieu Blondeel (2018) Fossil Fuel Subsidy Reform. In: Jakob Skovgaard & Harro Dirk van Asselt (eds) *The politics of fossil fuel subsidies and their reform*. Cambridge: Cambridge University Press, 83–99.

van der Kroon, Bianca; Roy Brouwer & Pieter J.H. van Beukering (2013) The energy ladder: Theoretical myth or empirical truth? Results from a meta-analysis. *Renewable and Sustainable Energy Reviews* 20: 504–513.

van Leeuwen, Richenda; Alex Evans & Besnik Hyseni (2017) Increasing the Use of Liquefied Petroleum Gas in Cooking in Developing Countries. *live wire* (2017/74). Washington, D.C.: World Bank (https://openknowledge.worldbank.org/handle/10986/26569).

Victor, David (2009) The Politics of Fossil-Fuel Subsidies. *Untold billions: fossil-fuel subsidies, their impacts and the path to reform*. The International Institute for Sustainable Development, Global Subsidies Initiative.

Wathore, Roshan; Kevin Mortimer & Andrew P. Grieshop (2017) In-Use Emissions and Estimated Impacts of Traditional, Natural- and Forced-Draft Cookstoves in Rural Malawi. *Environmental science & technology* 51(3): 1929–1938.

Weikmans, Romain & J. Timmons Roberts (2019) The international climate finance accounting muddle: is there hope on the horizon? *Climate and Development* 11(2): 97–111.

Whitley, Shelagh (2013) At cross-purposes: subsidies and climate compatible investment. London: Overseas Development Institute (ODI) April 2013 (http://www.odi.org.uk/publications/7343-subsidies-climate-compatible-investment-fossil-fuel-private-finance).

WHO (World Health Organization) (2006a) *Fuel for Life: Household Energy and Health*. Geneva: WHO Press (http://gbv.eblib.com/patron/FullRecord.aspx?p=763017).

WHO (World Health Organization) (2014) *WHO guidelines for indoor air quality: Household fuel combustion*. Geneva: World Health Organization.

WHO (World Health Organization) (2016) Burning opportunity: Clean household energy for health, sustainable development and wellbeing of women and children.

WHO (World Health Organization) (2019) Mortality from household air pollution (https://www.who.int/gho/phe/indoor_air_pollution/burden/en/).

WHO (World Health Organization Europe) (2006b) WHO Air quality guidelines for particulate matter, ozone, nitrogen dioxide and sulfur dioxide: Global update 2005. World Health Organization (https://apps.who.int/iris/handle/10665/69477).

Wooldridge, Jeffrey M. (2010) *Econometric analysis of cross section and panel data*. Cambridge, Mass.: MIT Press.

World Bank (1983) *The energy transition in developing countries*. Washington D.C.: World Bank.

World Bank (1992) *World Development Report 1992: Development and the Environment*. New York: Oxford University Press (https://openknowledge.worldbank.org/handle/10986/5975).

World Bank (2011) Household Cookstoves, Environment, Health, and Climate Change: A new look at an old problem. World Bank. Washington, D.C (http://documents.worldbank.org/curated/en/732691468177236006/Household-cookstoves-environment-health-and-climate-change-a-new-look-at-an-old-problem).

World Bank (2012) ACCES Africa Clean Cooking Energy Solutions Initiative: Scaling-Up Access to Clean Cooking Technologies and Fuels in Sub-Saharan Africa. World Bank. Washington, D.C.

World Bank (2016) World Development Indicators: (database) (http://databank.worldbank.org/data/reports.aspx?source=world-development-indicators).

World Bank (2017a) Putting Clean Cooking on the Front Burner. *Feature Story, December 21, 2017* (https://www.worldbank.org/en/news/feature/2017/12/21/putting-clean-cooking-on-the-front-burner).

World Bank (2017b) *World Bank Group Announcements at One Planet Summit*. Press Release No: 2018/087/CCG. Paris (https://www.worldbank.org/en/news/press-release/2017/12/12/world-bank-group-announcements-at-one-planet-summit).

World Bank (2020a) Carbon Pricing Dashboard: Up-to-date overview of carbon pricing initiatives (https://carbonpricingdashboard.worldbank.org/map_data).

World Bank (2020b) World Development Indicators: (database) (https://databank.worldbank.org/reports.aspx?source=world-development-indicators#).

WWF (World Wildlife Foundation) (2014) Cook stoves project combating deforestation in Madagascar gets an Earth Hour boost (https://wwf.panda.org).

Wylie, Blair J. (2017) The ghana randomized air pollution and health study (GRAPHS): A cluster-randomized trial of clean cookstoves to improve obstetric outcomes. *American Journal of Obstetrics and Gynecology* 216(1): Supplement 23.

YCELP (Yale Center For Environmental Law And Policy Yale University); CIESIN (Center For International Earth Science Information Network Columbia University) & WEF (World Economic Forum) 2016 Environmental Performance Index (EPI). NASA Socioeconomic Data and Applications Center. Palisades NY (https://doi.org/10.7927/H4FX77CS).

Zahno, Martina & Paula Castro (2017) Renewable energy deployment at the interplay between support policies and fossil fuel subsidies. In: Stefan E. Weishaar, Larry Kreiser, Janet E. Milne, Hope Ashiabor & Michael Mehling (eds) *The green market transition: Carbon* *taxes, energy subsidies and smart instrument mixes*. Critical issues in environmental taxation volume 19. Cheltenham, UK: Edward Elgar Publishing, 97–112.

Zahno, Martina; Katharina Michaelowa, Purnamita Dasgupta & Ishita Sachdeva (2020) Health awareness and the transition towards clean cooking fuels: Evidence from Rajasthan. *PloS one* 15(4): e0231931 (https://doi.org/10.1371/journal.pone.0231931).

Zhang, Yabei & Norma Adams (2016) Toward Universal Access to Clean Cooking and Heating: Early Lessons from the East Asia and Pacific Clean Stove Initiative. *live wire* (2016/62). World Bank. Washington, D.C. (https://openknowledge.worldbank.org/handle/10986/24257).